# This New Ocean



A History of Project Mercury

*Loyd S. Swenson, Jr.*
*James M. Grimwood*
*Charles C. Alexander*

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# This New Ocean

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*We set sail on this new sea because there is new knowledge to be gained, and new rights to be won, and they must be won and used for the progress of all people. For space science, like nuclear science and all technology, has no conscience of its own.*

*Whether it will become a force for good or ill depends on man, and only if the United States occupies a position of preeminence can we help decide whether this new ocean will be a sea of peace or a new, terrifying theater of war.*

JOHN F. KENNEDY
Rice University Stadium
Houston, Texas
September 12, 1962

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# This New Ocean

## A History of Project Mercury

*Loyd S. Swenson, Jr.*
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# FOREWORD

WHEN the Congress created the National Aeronautics and Space Administration in 1958, it charged NASA with the responsibility "to contribute materially to . . . the expansion of human knowledge of phenomena in the atmosphere and space" and "provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof." NASA wisely interpreted this mandate to include responsibility for documenting the epochal progress of which it is the focus. The result has been the development of a historical program by NASA as unprecedented as the task of extending man's mobility beyond his planet. This volume is not only NASA's accounting of its obligation to disseminate information to our current generation of Americans. It also fulfills, as do all of NASA's future-oriented scientific-technological activities, the further obligation to document the present as the heritage of the future.

The wide-ranging NASA history program includes chronicles of day-to-day space activities; specialized studies of particular fields within space science and technology; accounts of NASA's efforts in organization and management, where its innovations, while less known to the public than its more spectacular space shots, have also been of great significance; narratives of the growth and expansion of the space centers throughout the country, which represent in microcosm many aspects of NASA's total effort; program histories, tracing the successes—and failures—of the various projects that mark man's progress into the Space Age; and a history of NASA itself, incorporating in general terms the major problems and challenges, and the responses thereto, of our entire civilian space effort. The volume presented here is a program history, the first in a series telling of NASA's pioneering steps into the Space Age. It deals with the first American manned-spaceflight program: Project Mercury.

Although some academicians might protest that this is "official" history, it is official only in the fact that it has been prepared and published with the support and cooperation of NASA. It is not "official" history in the sense of presenting a point of view supposedly that of NASA officialdom—if anyone could determine what *the* "point of view" of such a complex organism might be. Certainly, the authors were allowed to pursue their task with the fullest freedom and in accordance with the highest scholarly standards of the history profession. They

were permitted unrestricted access to source materials and participants. Furthermore, they have with humility and some courage attempted to document what emerges as a complex accounting of the purposes of science, technology, and public funding in a challenging new area of human endeavor.

Some classical historians may deplore the short lapse of time between the actual events and the historical narration of them. Others may boggle at the mass of full documentary sources with which the Project Mercury historians have had to cope. There are offsetting advantages, however. The very freshness of the events and accessibility of their participants have made possible the writing of a most useful treatise of lasting historical value. Future historians may rewrite this history of Project Mercury for their own age, but they will indeed be thankful to their predecessors of the NASA historical program for providing them with the basic data as well as the view of what this pioneering venture in the Space Age meant to its participants and to contemporary historians.

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# PREFACE

MANKIND in the past few years has sailed on one of its greatest adventures, the exploration of near space. Men have cast off their physical and mental moorings to Earth, and a few have learned to live in balance with their gravisphere and above their atmosphere. Transgressing old laws of terrestrial navigation and amending newer laws of aerodynamics, man has combined the experience gained from aviation and rocket technology with the science of celestial mechanics, thus to accomplish for the first time manned orbital circumnavigation. The initial American voyages in this new epic of exploration and discovery were products of Project Mercury, an intensive national program mobilizing creative science and technology to orbit and retrieve a manned Earth satellite.

This book is an attempt to describe the origins, preparation, and nature of America's first achievements in manned space flight. Neither a history of the National Aeronautics and Space Administration (NASA) nor a comparative study of the competition in space between the United States and the Soviet Union, this narrative spans the basic events in the managerial and technological history of Project Mercury.

The authors have no illusions that this single volume is complete or "definitive" (if any work of history ever can be). Writing only a few years after the events described, we inescapably suffer from short perspective, but perhaps our scholarly myopia is balanced by our having had access to a multitude of still-dustless documents and to most of the main participants in Project Mercury. Within obvious limitations of chronology and the sensitivities of persons still active in the conquest of space, we have tried to make this narrative as comprehensive and accurate as possible in one volume.

Already Project Mercury has come to be regarded as a single episode in the history of flight and of the United States. Rather, it was many episodes, many people, many days of inspiration, frustration, and elation. Journalists and other contemporary observers have written millions of words, taken thousands of photographs, and produced hundreds of reports, official and otherwise, on the origins, development, failures, successes, and significance of this country's first efforts in the manned exploration of space. The foremost image of Mercury emerging from its mountainous publicity was that of seven selected test pilots called "astronauts." Central as were their roles and critical as were their risks in the individual manned flights, the astronauts themselves did not design, develop, or decide the means and

ends of the overall program. Thousands of engineers, scientists, technicians, and administrators, as well as the seven astronauts, cooperated to fulfill Mercury's goals, and this program history tries to blend and balance the personal, social, and technical facets of the project as it progressed.

Endeavoring to keep fickle human memories accurate in an age that moves incredibly fast in too many directions, we have sought to answer unanswered questions, to answer some questions that had not been asked, and even perhaps to pose some questions that cannot be answered yet. Written under sponsorship of NASA at its Manned Spacecraft Center (MSC) with principal reliance on a contract with the University of Houston, this study is, in the legal sense of the Space Act of 1958, an "official" history of Project Mercury. But NASA and its Historical Advisory Committee have wisely recognized that history should be written, taught, and finally judged by historians, and that the ultimate responsibility for historical generalizations and interpretations should rest with the authors. Accordingly, while we have trod circumspectly in places, we have been encouraged to arrive at historical judgments judiciously and independently. Thus there actually is no "official" NASA or MSC viewpoint on what happened. More details and acknowledgments on the historiography behind this work are to be found in the Note on Sources and Selected Bibliography at the end of the volume.

The organization and division of labor imposed on the narrative conforms to its chronology, to three genres of historical literature, and to the thesis that Project Mercury, from its inception in the fall of 1958, was preeminently an engineering, rather than a scientific, enterprise.

Part One, entitled "Research," could be called "origins" or "antecedents." This section on the long and complex "prehistory" of Project Mercury follows essentially a topical organization and might be seen as part of the external history of applied science. Emphasizing the contributions of individual minds and small groups of experimentalists, Part One recounts primarily progress in rocketry and research in space medicine, aerodynamics, and thermodynamics from the end of the Second World War to the inception of the first United States manned satellite project. The focus is on the evolutionary roles of the military services and the National Advisory Committee for Aeronautics, organizational nucleus of NASA.

Part Two, "Development," assumes with reason that all of the basic and most of the applied research necessary for undertaking a manned ballistic satellite project had been completed by October 1958. Thus the so-called research and development, or "R and D," phase of Mercury is mostly, if not entirely, "D" and corresponds to a relatively new professional interest, the history of technology. Part Two is a study of corporate technology in the crowded period during which the concurrent teamwork of previously diverse organizations drove toward placing a man in orbit around Earth.

For most people directly involved in Mercury, the dramatic "space race" aspect of the project was secondary to the accomplishment of an almost incredibly complex managerial and technological endeavor. Yet the historian cannot ignore

the broadly political and social context surrounding all of the organizing, contracting, innovating, manufacturing, training, and testing before the time in 1961 when men first rocketed into space. Costs, schedules, and "quality control"—the range of procedures designed to ensure reliability during space vehicle manufacturing and preparation for flight—were far less dramatic than the flights themselves. But the NASA Space Task Group, primarily responsible for the development of Mercury, had an exciting life of its own as it evolved into the Manned Spacecraft Center. The Mercury team was much larger than the Space Task Group, or even than NASA, but the focus in Part Two on the field managers of the project should be meaningful for anyone wishing insight into the enormity and intricacy of modern government-managed technological programs.

Part Three, entitled "Operations," describes the fulfillment of Project Mercury and the only part of the program witnessed by most contemporary observers. This section begins with the successful suborbital flight of Astronaut Alan B. Shepard, Jr., in May 1961; proceeds through the completion of the orbital qualification of the Mercury spacecraft and the Atlas rocket; and ends with the four manned orbital missions, stretching from three to 22 circuits of Earth, in 1962 and 1963. Part Three is allied with a heroic tradition, the history of exploration and discovery.

Cosmonaut Yuri A. Gagarin first made a space flight around Earth on April 12, 1961, and four months later Gherman Titov's 17-orbit flight pushed the U.S.S.R. still further ahead in the cold war space competition. With American technological prestige damaged in the court of world opinion, the United States responded after Shepard's suborbital ride, when President John F. Kennedy proposed and an eager Congress agreed to make Mercury the first phase of an epochal national venture in the manned exploration of the Earth-Moon system.

Although the Soviet Union succeeded in orbiting more space travelers, for longer periods, and sooner than the United States, Project Mercury still appears magnificently successful. It cost more money and took more time than originally expected, but no precaution was overlooked and no astronaut was lost. And as the "space race" broadened into the "space olympics," Mercury evolved from a "dead-end" endeavor, pointed solely at achieving orbital flight and recovery, into a prerequisite course in what was needed to reach and return from the Moon.

If Mercury was not all that it might have been, it was certainly more than it originally was supposed to be. Less than three and a half years after its inception, its prime objectives were attained with the three-orbit flight of Astronaut John H. Glenn, Jr. In all, the Mercury astronauts flew two ballistic, parabolic flights into space and four orbital missions. Each flight went almost as well as planned, thereby substantially enlarging man's knowledge of near space, of his psychophysiological behavior beyond Earth's atmosphere, and of the impending requirements for cislunar travel. By June 12, 1963, when James E. Webb, the second NASA Administrator, announced its termination, Project Mercury had

become the focal point of the American people's vicarious journey into space, the first rung on a ladder leading to the Moon, and perhaps beyond.

This volume, therefore, represents an effort to lift out of anonymity, where so much of mankind's technological progress lies buried, the odyssey of the men who developed the means for escaping our age-old habitat. We hope to enlarge man's knowledge of himself by recording who did what, when, and where to achieve the confidence and provide the machines for space flight. We have aimed to supply a reference to the past, a benchmark for the present, and a source for future scholarship. Later historians will write about Gemini and Apollo, and about Ranger, Mariner, and other projects in space exploration by men of our times. But like students of Mercury, present and future, they must begin with an accurate record of technological achievement. In time, perhaps, Project Mercury may deserve more, because it was both an effect of and a cause for the faith, vision, and prowess necessary to explore space.

☿ ☿ ☿ ☿ ☿ ☿ ☿ ☿ ☿ ☿

This history of Project Mercury is, in more than the usual sense, drawn from the memory of many of the primary participants in the program. They provided much of the documentation upon which this narrative is based, and some 150 of them have commented upon all or parts of a review edition before publication. They are not responsible, however, for the selection, organization, or interpretations of facts as here presented. If errors persist in this account, the fault lies solely with the authors.

A different emphasis might have been pursued in this history—perhaps, for instance, more on the management of manned space programs. But Project Mercury per se is the focus herein, and as history it is meant to be read consecutively. In the launching of this history, the endorsement and support of the late Hugh L. Dryden, Deputy Administrator of NASA (1958–1965); Chancellor George L. Simpson of the University of Georgia System, former Assistant Deputy Administrator (1962–1965); and Robert R. Gilruth, Director of the Manned Spacecraft Center, proved instrumental. Whatever value this volume may have in reflecting the broader concerns of NASA Headquarters results largely from the contributions of Eugene M. Emme, the NASA Historian, and Frank W. Anderson, the Deputy NASA Historian. They have minutely read and criticized the draft manuscripts and coordinated the details of publication.

Paul E. Purser, Special Assistant to the Director, Manned Spacecraft Center, and Allen J. Going, Chairman, Department of History, University of Houston, have read various phases of the draft work and suggested improvements at every step. Sigman Byrd and Pamela C. Johnson worked with the authors as editorial and research assistants in its formative stages. Ivan D. Ertel made the final index and basic selection of illustrations. Sally D. Gates made many invaluable editorial suggestions and comments, typed several "final" drafts, and administratively

coordinated the review edition with the numerous readers. Geri A. Vanderoef typed many of the early manuscripts in the constant revision process.

Among those NASA field center historians and monitors who have been most helpful are David S. Akens of the Marshall Space Flight Center; Alfred Rosenthal of the Goddard Space Flight Center; Robert A. Lindemann and Francis E. Jarrett, Jr., of the Kennedy Space Center; Manley Hood and John B. Talmadge of the Ames Research Center; Lyndell L. Manley of the Lewis Research Center; and Robert W. Mulac of the Langley Research Center.

Government—particularly Air Force—and industrial historians, librarians, and archivists too numerous to mention offered courteous assistance on many aspects of Project Mercury. William D. Putnam, Office of Manned Space Flight and formerly of the Air Force Space Systems Division; Max Rosenberg of the Air Force Historical Liaison Office; Charles V. Eppley, Air Force Flight Test Center; Marvin E. Hintz, Air Force Arnold Engineering Development Center; Green Peyton of the Air Force School of Aerospace Medicine; Michael Witunski of the McDonnell Aircraft Corporation; Ralph B. Oakley of North American Aviation; and Louis Canter of General Dynamics/Astronautics deserve special mention and thanks.

At the Manned Spacecraft Center, the Public Affairs Office, under Paul P. Haney and Albert M. Chop, provided documentation, contract support, and many hours of critical reading; the Technical Library, through the efforts of Retha Shirkey, furnished literature; and the Technical Information Division's Robert W. Fricke helped immeasurably in securing documentation.

Countless others also should be mentioned for their aid on specific questions, but most of them have been credited in the citations.

L.S.S.
J.M.G.
C.C.A.

*January 1966*

# *Part One*

# RESEARCH

# I

# The Lure, the Lock, the Key

(TO 1958)

THE yearning of men to escape the confines of their Earth and to travel to the heavens is older than the history of mankind itself. Religion, mythology, and literature reaching back thousands of years are sprinkled with references to magic carpets, flying horses, flaming aerial chariots, and winged gods.[1] Although "science fiction" is a descriptive term of recent vintage, the fictional literature of space travel dates at least from the second century A.D. Around the year 160 the Greek savant Lucian of Samosata wrote satirically about an imaginary journey to the Moon, "a great countrie in the aire, like to a shining island," as Elizabethan scholars translated his description 1500 years later. Carried to the Moon by a giant waterspout, Menippus, Lucian's hero, returns to Earth in an equally distinctive manner: The angry gods simply have Mercury take hold of his right ear and deposit him on the ground. Lucian established a tradition of space-travel fiction, and generations of later storytellers spawned numerous fantasies in which by some miraculous means—such as a flight of wild lunar swans in a seventeenth-century tale by Francis Godwin or a cannon shot in Jules Verne's classic account of a Moon voyage (1865–1870)—earthlings are transported beyond the confines of their world and into space.[2]

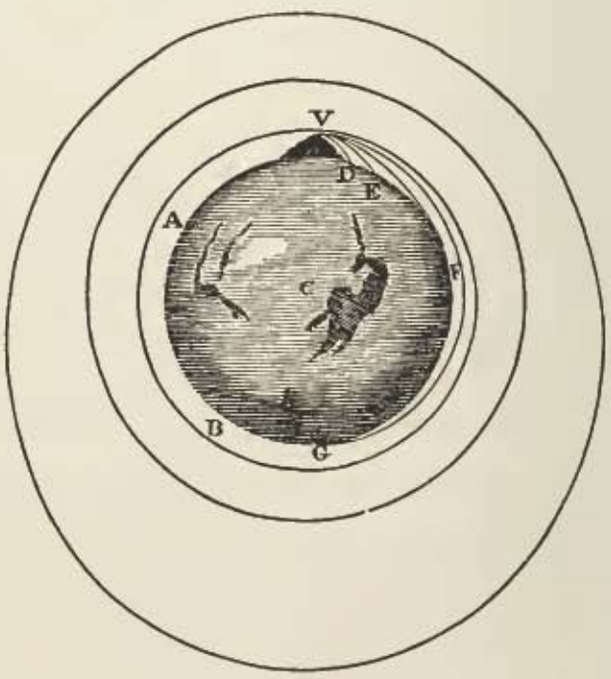
But apparently the first suggestion, fictional or otherwise, for an artificial manned satellite of Earth is to be found in a short novel called "The Brick Moon," written in 1869 by the American Edward Everett Hale and originally serialized in the *Atlantic Monthly*. Although, like most of his contemporaries, Hale had only a vague notion of where Earth's atmosphere ended and where space began, he did realize that somewhere the "aire" became the "aether," and he also understood the mechanics of putting a satellite into an Earth orbit:

> If from the surface of the earth, by a gigantic peashooter, you could shoot a pea upward . . . ; if you drove it so fast and far that when its power of ascent was exhausted, and it should fall, it should clear the earth . . . ; if you had given it sufficient power to get it half way round the earth without touching, that pea would clear the earth forever. It would continue to rotate . . . with the impulse with which it had first cleared our atmosphere and attraction.



*Doré's mid-19th century illustration, "A Voyage to the Moon," captured man's age-old dream of lifting himself off Earth and venturing out toward our celestial neighbors, the Moon, the Sun, the planets, and even the stars.*

*The action of centripetal forces as advanced by Isaac Newton: "That by means of centripetal forces the planets may be retained in certain orbits, we may easily understand, if we consider the motions of projectiles; for a stone that is projected is by the pressure of its own weight forced out of the rectilinear path, which by the initial projection alone it should have pursued, and made to describe a curved line in the air; and through that crooked way is at last brought down to the ground; and the greater the velocity is with which it is projected, the farther it goes before it falls to the earth. We may therefore suppose the velocity to be so increased, that it would describe an arc of 1, 2, 5, 10, 100, 1,000 miles before it arrived at earth, till at last, exceeding the limits of the earth, it should pass into space without touching it."*



In Hale's story a group of industrious New Englanders construct a 200-foot-diameter brick sphere, which, carrying 37 people, is prematurely hurled into an orbit 4000 miles from Earth by two huge flywheels.[3] Less than a hundred years later, Hale's own country would undertake a more modest and more practicable scheme for a manned satellite in Project Mercury.

Centuries before Hale wrote about an orbiting manned sphere, Nicolaus Copernicus, Johannes Kepler, Galileo Galilei, and other astronomers had helped put the solar system in order, with the Sun in the center and the various planets, spherical and of different sizes, orbiting elliptically around it. Isaac Newton had established the basic principles of gravitation and mechanics governing reaction propulsion and spatial navigation.[4] Thus it was possible for Hale and his fellow-fictionists to think at least half seriously about, and to describe in fairly accurate detail, such adventures as orbiting Earth and its Moon and voyaging to Venus.

Most flight enthusiasts in the nineteenth century, however, were absorbed with the problems of flight within the atmosphere, with conveyance from one place to another on Earth. This preoccupation with atmospheric transport, which would continue until the mid-twentieth century, in many ways retarded interest in rocketry and space travel. But the development and refinement of aeronautics in the twentieth century was both a product of and a stimulant to man's determination to fly ever higher and faster, to travel as far from his Earth as he could. Atmospheric flight, in terms of both motivation and technology, was a necessary prelude to the exploration of near and outer space. In a sense, therefore, man's journey along the highway to space, leading to such astronautical achievements as Project Mercury, began in the dense forest of his atmosphere, with feats in aeronautics.

## Conquest of the Air

Man first ventured aloft in balloons in the 1780s, and in the next century gliders also bore human passengers on the air. By 1900 a host of theoreticians and inventors in Europe and the United States were steadily expanding their knowledge and capability beyond the flying of balloons and gliders and into the complexities of machineborne flight. The essentials of the airplane—wings, rudders, engine, and propeller—already were well known, but what had not been done was to balance and steer a heavier-than-air flying machine.

On December 8, 1903, Samuel Pierpont Langley, a renowned astrophysicist and Secretary of the Smithsonian Institution, tried for the second time to fly his manned "aerodrome," a glider fitted with a small internal combustion engine, by catapulting it from a houseboat on the Potomac River. The much-publicized experiment, financed largely by the United States War Department, ended in failure when the machine plunged, with pilot-engineer Charles M. Manley, into the cold water.[5] The undeserved wave of ridicule and charges of waste that followed Langley's failure obscured what happened nine days later at Kitty Hawk, North Carolina. There two erstwhile bicycle mechanics from Dayton,

Ohio, Wilbur and Orville Wright, carried out "the first [flight] in the history of the world in which a machine carrying a man had raised itself by its own power into the air in full flight, had sailed forward without reduction of speed, and had finally landed at a point as high as that from which it started."[6] Although few people realized it at the time, practicable heavier-than-air flight had become a reality.

The United States Army purchased the first military airplane, a Wright Flyer, in 1908. But when Europe plunged into general war in 1914, competitive nationalism—drawing on the talents of scientists like Ernst Mach in Vienna, Ludwig Prandtl in Germany, and Osborne Reynolds in Great Britain, and of inventors like the Frenchmen Louis Bleriot and Gabriel Voisin—had accelerated European flight technology well beyond that of the United States.[7] In 1915, after several years of agitation for a Government-financed "national aeronautical laboratory" like those already set up in the major European countries, Congress took the first step to regain the leadership in aeronautics that the United States had lost after 1908. By an amendment attached to a naval appropriation bill, Congress established an Advisory Committee for Aeronautics "to supervise and direct the scientific study of the problems of flight, with a view to their practical solution." President Woodrow Wilson, who at first had feared that the creation of such an organization might reflect on official American neutrality, appointed the stipulated 12 unsalaried members to the "Main Committee," as the policymaking body of the new organization came to be called. At its first meeting, the Main Committee changed the name of the organization to National Advisory Committee for Aeronautics, and shortly "NACA" began making surveys of the state of aeronautical research and facilities in the country. During the First World War it aided significantly in the formulation of national policy on such critical problems as the cross-licensing of patents and aircraft production. NACA did not have its own research facilities, however, until 1920, when it opened the Langley Memorial Aeronautical Laboratory, named after the "aerodrome" pioneer, at Langley Field, Virginia.[8]

In the 1920s and 1930s aeronautical science and aviation technology continued to advance, as the various cross-country flights, around-the-world flights, and the most celebrated of all aerial voyages, Charles A. Lindbergh's nonstop flight in 1927 from New York to Paris, demonstrated. During these decades NACA brought the United States worldwide leadership in aeronautical science. Concentrating its research in aerodynamics and aerodynamic loads, with lesser attention to structural materials and powerplants, NACA worked closely with the Army and Navy laboratories, with the National Bureau of Standards, and with the young and struggling aircraft industry to enlarge the theory and technology of flight.[9] The reputation for originality and thorough research that NACA quietly built in the interwar period would continue to grow until 1958, when the organization would metamorphose into a glamorous new space agency, the likes of which might have frightened the early NACA stalwarts.



## Early Aviation

*Man's liberation from the surface of Earth began at Kitty Hawk, N.C., on December 17, 1903, when Orville and Wilbur Wright made the world's first controlled, powered flights in a heavier-than-air machine (above). At last it was within man's grasp to use Earth's atmosphere as a means of transportation. There was much to learn; in the United States the National Advisory Committee for Aeronautics pioneered aeronautical research in the 1920s. Early wind tunnel research at Langley Memorial Aeronautical Laboratory (right) culminated in the famous NACA cowling and the family of NACA wing shapes that would dominate several generations of aircraft from the 1920s into the 1940s. And aviation finally came of age in world opinion with the epochal solo flight from New York to Paris by Charles E. Lindbergh, May 20–21, 1927. Lindbergh and his plane, the "Spirit of St. Louis," are shown (below, right) visiting the Washington Navy Yard on June 11, 1927.*





Over the years NACA acquired a highly competent staff of "research engineers" and technicians at its Langley laboratory.[10] Young aeronautical and mechanical engineers just leaving college were drawn to NACA by the intellectual independence characterizing the agency, by the opportunity to do important work and see their names on regularly published technical papers, and by the superior wind tunnels and other research equipment increasingly available at the Virginia site. NACA experimenters made discoveries leading to such major innovations in aircraft design as the smooth cowling for radial engines, wing fillets to cut down on wing-fuselage interference, engine nacelles mounted in the wings of multiengine craft, and retractable landing gear. This and other research led to the continual reduction of aerodynamic drag on aircraft shapes and consequent increases in speed and overall performance.[11]

The steady improvement of aircraft design and performance benefited commercial as well as military aviation. Airlines for passenger, mail, and freight transport, established in the previous decade both in the United States and Europe, expanded rapidly in the depression years of the thirties. In the year 1937 more than a million passengers flew on airlines in the United States alone.[12] At the same time, advances in speed, altitude, and distance, together with numerous innovations in flight engineering and instrumentation, presaged the arrival of the airplane as a decisive military weapon.[13]

Yet NACA remained small and inconspicuous; as late as the summer of 1939 its total complement was 523 people, of whom only 278 were engaged in research activities. Its budget for that fiscal year was $4,600,000.[14] The prevailing mood of the American public throughout the thirties was reflected in the neutrality legislation passed in the last half of the decade, in niggardly defense appropriations, and in the preoccupation of the Roosevelt administration with the domestic aspects of the Great Depression. Without greatly increased appropriations from Congress, the military was held back in its efforts to acquire more and better aerial weapons. Without a military market for its products, the American aircraft industry proceeded cautiously and slowly in the design and manufacture of airframes and powerplants. And in the face of the restricted needs of industry and the armed services and severly limited appropriations, NACA kept its efforts focused where it could acquire the greatest quantity of knowledge for the smallest expenditure of funds and manpower—in aerodynamics.

As Europe moved nearer to war, however, the Roosevelt administration, Congress, and the public at large showed more interest in an expanded military establishment, including military aviation. Leading figures like Lindbergh and Vannevar Bush, president of the Carnegie Institution and chairman of the Main Committee, warned of the remarkable gains in aviation being made in other countries, especially in Nazi Germany.[15] While the United States may have retained its aerodynamics research lead, the Germans, drawing, in part from the published findings of NACA, by 1939 had temporarily outstripped this country in aeronautical development.

After the outbreak of war in Europe, NACA eventually secured authorization and funding to increase its program across the board, including a much enlarged effort in propulsion and structural materials research. A new aeronautical laboratory, named after physicist Joseph S. Ames of Johns Hopkins University, former chairman of the Main Committee, was constructed beginning in 1940 on land adjacent to the Navy installation at Moffett Field, California, 40 miles south of San Francisco. The next year, on a site next to the municipal airport at Cleveland, NACA broke ground for still another laboratory, to be devoted primarily to engine research. In later years the Cleveland facility would be named the Lewis Flight Propulsion Laboratory, after George W. Lewis, for 28 years NACA's Director of Research.[16]

Some nine months before Pearl Harbor, Chairman Bush of NACA appointed a Special Committee on Jet Propulsion, headed by former Main Committeeman William F. Durand of Stanford University, and including such leaders in aeronautical science as Theodore von Kármán of the California Institute of Technology and Hugh L. Dryden of the National Bureau of Standards.[17] Until then NACA, the military services, and the aircraft industry had given little attention to jet propulsion. There had been little active disagreement with the conclusion reached in 1923 by Edgar Buckingham of the Bureau of Standards: "Propulsion by the reaction of a simple jet cannot complete, in any respect, with air screw propulsion at such flying speeds as are now in prospect." [18] By 1941, however, Germany had flown turbojets, and her researchers were working intensively on the development of an operational jet-propelled interceptor. In Britain the propulsion scientist Frank Whittle had designed and built a gas-turbine engine and had flown a turbojet-powered aircraft.

Faced with the prospect of European-developed aircraft that could reach flight regimes in excess of 400 miles per hour and operational altitudes of about 40,000 feet, NACA gradually authorized more and more research on jet powerplants for the Army Air Forces and the Navy. Most of the NACA research effort during the war, however, went to "quick fixes," improving or "cleaning up" military aircraft already produced by aircraft companies, rather than to the more fundamental problems of aircraft design, construction, and propulsion.[19] So, understandably and predictably, during the Second World War, Germany was first to put into operation military aircraft driven by jet powerplants, as well as rocket-powered interceptors that could fly at 590 miles per hour and climb to 40,000 feet in two and a half minutes.[20] The German jets and rocket planes came into the war too late to have any effect on its outcome, but the new aircraft caused consternation among American aeronautical scientists and military planners.

The Second World War saw, in the words of NACA Chairman Jerome C. Hunsaker, "the end to the development of the airplane as conceived by Wilbur and Orville Wright." [21] Propeller-driven aircraft advanced far beyond their original reconnaissance and tactical uses and became integral instruments of strategic warfare. The development of the atomic bomb meant a multifold

increase in the firepower of aircraft, but well before the single B–29 dropped the single five-ton bomb on Hiroshima, long-range bomber fleets carrying conventional TNT explosives and incendiaries had radically altered the nature of war.[22]

The frantic race in military technology developing in the postwar years between the United States and the Soviet Union produced a remarkable acceleration in the evolution of the airplane. Jet-propelled interceptors, increasingly rakish in appearance by comparison with their staid propeller-driven ancestors, flew ever faster, higher, and farther.[23] Following the recommendations of a series of blue-ribbon scientific advisory groups, the Defense Department and the newly independent Air Force made the Strategic Air Command, with its thousands of huge manned bombers, the first line of American defense in the late forties and early fifties.[24] To many people the intercontinental bomber, carrying fission and (after 1954) hydrogen-fusion weapons, capable of circumnavigating the globe nonstop with mid-air refueling, looked like the "ultimate weapon" men had sought since the beginning of human conflict.

Working under the incessant demands of the cold-war years, NACA continued to pioneer in applied aeronautical research. By 1946 the NACA staff had grown to about 6800, its annual budget was in the vicinity of $40 million, and its facilities were valued at more than $200 million. Although Chairman Hunsaker and others on the Main Committee felt that NACA's principal mission should be inquiry into the fundamentals of aeronautics, the military services and the aircraft industry continued to rely on NACA as a problem-solving agency. The pressure for "quick fixes" persisted as the Korean War intensified requirements for work on specific aircraft problems.[25]

The outstanding general impediment to aeronautical progress, however, continued to be the so-called "sonic barrier," a region near the speed of sound (approximately 750 miles per hour at sea level, 660 miles per hour above 40,000 feet) wherein an aircraft encounters compressibility phenomena in fluid dynamics, or the "piling up" of air molecules. A serious technical obstacle to high-speed research in the postwar years was the choking effect experienced in wind tunnels during attempts to simulate flight conditions in the transonic range (600–800 miles per hour). A wind tunnel constructed at Langley employing the slotted-throat principle to overcome the choking phenomenon did not begin operation until 1951, and a series of NACA and Air Force supersonic tunnels, authorized by Congress under the Unitary Plan Act of 1949, was not completed until the mid-fifties.[26] NACA investigators had to use other methods for extensive transonic research. One was a falling-body technique, in which airplane models equipped with radio-telemetry apparatus were dropped from bombers at high altitudes. Another was the firing of small solid-propellant rockets to gather data on various aerodynamic shapes accelerated past mach 1, the speed of sound. Many of these tests supported military missile studies. The rocket firings were carried out at the Pilotless Aircraft Research Station, a facility set up by the Langley laboratory on Wallops Island, off the Virginia coast, in the spring of 1945. The Pilot-

less Aircraft Research Division at Langley, until the early fifties headed by Robert R. Gilruth, conducted the NACA program of aerodynamic research with rocket-launched models.[27]

The most celebrated part of the postwar aeronautical research effort in the United States, however, was the NACA-military work with rocket-propelled aircraft. In 1943, Langley aerodynamicist John Stack and Robert J. Woods of the Bell Aircraft Corporation, realizing that propeller-driven aircraft had about reached their performance limits, suggested the development of a special airplane for research in the problems of transonic and supersonic flight. The next year, the Army Air Forces, the Navy, and NACA inaugurated a program for the construction and operation of such an airplane, to be propelled by a liquid-fueled rocket engine. Built by Bell and eventually known as the X–1, the plane was powered by a 6000-pound-thrust rocket burning liquid oxygen and a mixture of alcohol and distilled water. On October 14, 1947, above Edwards Air Force Base in southern California, the X–1 dropped from the underside of its B–29 carrier plane at 35,000 feet and began climbing. A few seconds later the pilot of the small, bullet-shaped craft, Air Force Captain Charles E. Yeager, became the first man officially to fly faster than the speed of sound in level or climbing flight.[28]

The X–1 was the first of a line of generally successful rocket research airplanes. In November 1953 the Navy's D–558–II, built by the Douglas Aircraft Company and piloted by A. Scott Crossfield of NACA, broke mach 2, twice sonic speed; but this record stood only until the next month, when Yeager flew the new Bell X–1A to mach 2.5, or approximately 1612 miles per hour. The following summer Major Arthur Murray of the Air Force pushed the X–1A to a new altitude record of 90,000 feet above the Mojave Desert test complex consisting of Edwards Air Force Base and NACA's High Speed Flight Station. These spectacular research flights, besides banishing the myth that aircraft could not fly past the "sonic barrier," affected the design and performance of tactical military aircraft.[29] In the early fifties, the Air Force and the aircraft industry, profiting from the mountain of NACA research data, were preparing to inaugurate the new "century series" of supersonic jet interceptors.[30] And representatives of NACA, the Air Force, and the Navy Bureau of Aeronautics already were planning a new experimental rocket plane, the X–15, to employ the most powerful rocket aircraft motor ever developed and to fly to an altitude of 50 miles, the very edge of space.

Thus less than a decade after the end of the Second World War, airplanes—jet-powered and rocket-propelled—had virtually finished exploring the sensible atmosphere, the region below 80,000 or 90,000 feet. Much work remained for aeronautical scientists and engineers in such areas as airflow, turbulence, engines, and fuels, but researchers in NACA, the military, and the aircraft industry approached the thorniest problems in aeronautics with a confidence grounded in 50 years of progress. Man's facility in atmospheric flight and his adjustment to the airplane seemed complete. Pilots had mastered some of the most complex moving machines ever contrived, and passengers sat comfortably and safely in




*The famous research aircraft series is shown above: in the center, the Douglas X–3; lower left, the Bell X–1A; continuing left to right, the Douglas D–558–I, the Convair XF–92A, the Bell X–5, the Douglas D–558–II, and the Northrop X–4. In the photo below, the X–15 is shown as it drops away from its mother B–52 and starts its own 57,000-lb.-thrust engine to begin another of its highly successful research flights.*



pressurized cabins on high-altitude airliners featuring an unprecedented combination of speed and luxury. It appeared that man at last had accomplished what the ancients had dreamed of—conquest of the air.

## The Highway to Space

Space flight, however, was something else. While in one sense atmospheric flight was the first step toward space flight, extra-atmospheric transport involves much more than a logical extension of aviation technology. The airplane, powered either by a reciprocating or a jet engine, is a creature and a captive of the atmosphere, because either powerplant depends on air—more properly, oxygen—for its operation, and in space there is no air. But the rocket, unlike the gas turbine, pulsejet, ramjet, or piston engine, needs no air. It carries everything needed for propulsion within itself—its own fuel and some form of oxidizer, commonly liquid oxygen, to burn the fuel. So the rocket engine operates independently of its environment; in fact, its efficiency increases as it climbs away from the frictional density of the lower atmosphere to the thin air of the stratosphere and into the airlessness of space.[31]

Yet even the rocket research airplanes were a long way from spacecraft. Although some of these vehicles provided data on the use of reaction controls for steering in the near vacuum of the upper atmosphere, they were designed to produce considerable aerodynamic lift for control within the lower atmosphere; and, in terms of the mass to be accelerated, their powerplants burned too briefly and produced too little thrust to counterbalance the oppressive force of gravity. Fulfillment of the age-old desire to travel to the heavens, even realization of Hale's nineteenth-century concept of a manned sphere circling Earth in lower space, would have to await the development of rockets big enough to boost thousands of pounds and to break the lock of gravity.

Although black-powder rockets, invented by the Chinese, had been used for centuries for festive and military purposes, not until the late nineteenth and early twentieth centuries did imaginative individuals in various parts of the world begin seriously to consider the liquid-fueled rocket as a vehicle for spatial conveyance. The history of liquid-fueled rocketry, and thus of manned space flight, is closely linked to the pioneering careers of three men—the Russian Konstantin Eduardovich Tsiolkovsky (1857–1935), the American Robert Hutchings Goddard (1882–1945), and the German-Romanian Hermann Oberth (1894– ).

Tsiolkovsky, for most of his life an obscure teacher of mathematics, authored a series of remarkable technical essays on such subjects as reaction propulsion with liquid-propellant rockets, attainable velocities, fuel compositions, and oxygen supply and air purification for space travelers. He also wrote what apparently was the first technical discussion of an artificial Earth satellite.[32] Although virtually unknown in the West at the time of his death, in 1935, Tsiolkovsky was honored by the Soviets and had helped establish a long Russian tradition of

astronautics. This tradition helps to account for the U.S.S.R.'s advances with rocket-assisted airplane takeoffs and small meteorological rockets of the 1930s and her space achievements of the 1950s and 1960s.[33]

In terms of experimentation, Goddard, professor of physics at Clark University, was by far the most important of the rocket pioneers.[34] As early as 1914 he secured a patent for a small liquid-fueled rocket engine. Six years later he published a highly technical paper on the potential uses of a rocket with such an engine for studying atmospheric conditions at altitudes from 20 to 50 miles. Toward the end of the paper he mentioned the possibility of firing a rocket containing a powder charge that could be exploded on the Moon. "It remains only to perform certain necessary preliminary experiments before an apparatus can be constructed that will carry recording instruments to any desired altitude," he concluded.[35]

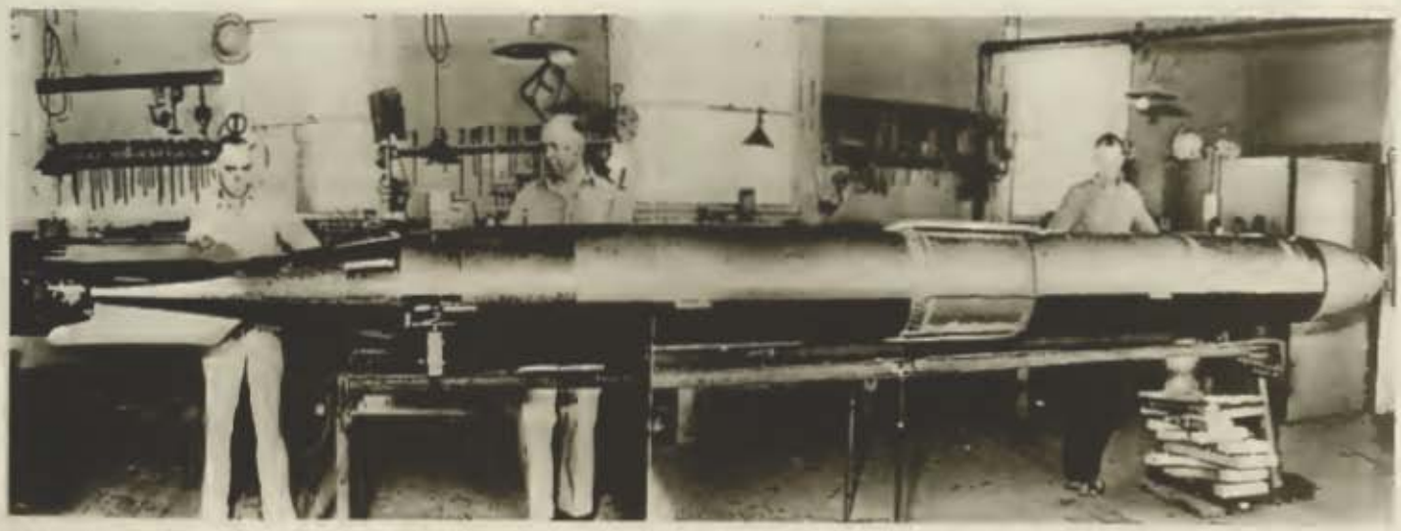
Goddard's life for the next 20 years was devoted to making those "necessary preliminary experiments." Working in the 1920s in Massachusetts with financial support from various sources and in the New Mexico desert with Guggenheim Foundation funds during the succeeding decade, Goddard compiled an amazing list of "firsts" in rocketry. Among other things, he carried out the first recorded launching of a liquid-propellant rocket (March 16, 1926), adapted the gyroscope to guide rockets, installed movable deflector vanes in a rocket exhaust nozzle for stability and steering, patented a design for a multistage rocket, developed fuel pumps for liquid-rocket motors, experimented with self-cooling and variable-thrust motors, and developed automatically deployed parachutes for recovering his instrumented rockets. Finally, he was the first of the early rocket enthusiasts to go beyond theory and design into the realm of "systems engineering"—the complex and hand-dirtying business of making airframes, fuel pumps, valves, and guidance devices compatible, and of doing all the other things necessary to make a rocket fly. Goddard put rocket theory into practice, as his 214 patents attest.[36]

Goddard clearly deserves the fame that has attached to his name in recent years, but in many ways he was more inventor than scientist. He deliberately worked in lonely obscurity, jealously patented virtually all of his innovations, and usually refused to share his findings with others. Consequently his work was not as valuable as it might have been to such of his contemporaries as the young rocket buffs who formed the American Rocket Society in the early thirties and vainly sought his counsel.[37]

Goddard's disdain for team research prompted his refusal to work with the California Institute of Technology Rocket Research Project, instigated in 1936 by the renowned von Kármán, then director of the Guggenheim Aeronautical Laboratory at CalTech. The CalTech group undertook research in the fundamentals of high-altitude sounding rockets, including thermodynamics, the principles of reaction, fuels, thrust measurements, and nozzle shapes. Beginning in 1939 the Guggenheim Laboratory, under the first Federal contract for rocket

*From theory through laboratory demonstration through design, construction, test flight, and use of payload, Robert H. Goddard must rank as the U.S. pioneer in modern rocketry. The famous photo at the right shows Goddard beside his first successful liquid-fuel rocket, flown March 16, 1926. Years later, in the spring of 1941, he had progressed to larger, more complex models, like the one shown below in his workshop at Mescalero Ranch, Roswell, N. Mex., with his assistants. In December 1944, Goddard sent this photo to his long-time benefactor Harry F. Guggenheim with the comment, "It is practically identical with the German V–2 rocket."*





research, carried out studies and experiments for the Army Air Forces, especially on rocket-assisted takeoffs for aircraft. These takeoff rockets were called JATO (for "Jet-Assisted Take-Off") units, because, as one of the CalTech scientists recalled, "the word 'rocket' was of such bad repute that [we] felt it advisable to drop the use of the word. It did not return to our vocabulary until several years later . . . ." [38] In 1944, with the Guggenheim Laboratory working intently on Army and Navy contracts for JATO units and small bombardment rockets, the Rocket Research Project was reorganized as the Jet Propulsion Laboratory.[39]

In the 1920s and 1930s interest in rocketry and space exploration became firmly rooted in Europe, although the rapid expansion of aviation technology occupied the attention of most flight-minded Europeans. Societies of rocket theorists and experimenters, mostly privately sponsored, were established in several European countries.[40] The most important of these groups was the Society for Space Travel (*Verein für Raumschiffahrt*), founded in Germany but having members in other countries. The "*VfR*," as its founders called it, gained much of its impetus from the writings of Oberth, who in 1923, as a young mathematician, published his classic treatise on space travel, *The Rocket into Interplanetary Space*. A substantial portion of this small book was devoted to a detailed description of the mechanics of putting into orbit a satellite of Earth.[41]

Spurred by Oberth's theoretical arguments, the Germans in the *VfR* in the early thirties conducted numerous static firings of rocket engines and launched a number of small rockets. Meanwhile the German Army, on the assumption that rocketry could become an extension of long-range artillery and because the construction of rockets was not prohibited by the Treaty of Versailles, had inaugurated a modest rocket development program in 1931, employing several of the *VfR* members. One of these was a 21-year-old engineer named Wernher von Braun, who later became the civilian head of the army's rocket research group. In 1933 the new Nazi regime placed all rocket experimentation, including that being done by the rest of the *VfR*, under strict government control.[42]

The story of German achievements in military rocketry during the late thirties and early forties at Peenemuende, the vast military research installation on the Baltic Sea, is well known.[43] Knowing Goddard's work only through his published findings, the German experimenters contrived and elaborated on nearly all of the American's patented technical innovations, including gyroscopic controls, parachutes for rocket recovery, and movable deflector vanes in the exhaust. The rocket specialists at Peenemuende were trying to create the first large, long-range military rocket. By 1943, after numerous frustrations, they had their "big rocket," 46 feet long by 11½ feet in diameter, weighing 34,000 pounds when fueled, and producing 69,100 pounds of thrust from a single engine consuming liquid oxygen and a mixture of alcohol and water. Called "Assembly–4" (A–4) by the Peenemuende group, the rocket had a range of nearly 200 miles and a maximum velocity of about 3500 miles per hour, and was controlled by its

gyroscope and exhaust deflector vanes, sometimes supplemented by radio control.[44] When Major General Walter Dornberger, commander of the army works at Peenemuende, pronounced the A–4 operational in 1944, Joseph Goebbels' propaganda machine christened it *Vergeltungswaffe zwei* (Vengeance Weapon No. 2), or "V–2."[45] But for the space-travel devotees at Peenemuende the rocket remained the A–4, a step in the climb toward space.

Although the total military effect of the 3745 V–2s fired at targets on the Continent and in England was slight, this supersonic ballistic missile threw a long shadow over the future of human society. As the Western Allies and the Soviets swept into Germany, they both sought to confiscate the elements of the German rocket program in the form of records, hardware, and people. Peenemuende was within the Russian zone of occupation, but before the arrival of the Soviet forces von Braun and most of the other engineers and technicians fled westward with a portion of their technical data. The Americans also captured the underground V–2 factory in the Harz Mountains; 100 partially assembled V–2s were quickly dismantled and sent to the United States. Ultimately von Braun and about 125 other German rocket specialists reached this country under "Project Paperclip," carried out by the United States Army.[46]

The Soviets captured no more than a handful of top Peenemuende engineers and administrators. "This is absolutely intolerable," protested Josef Stalin to



*Hermann Oberth with key officials of the Army Ballistic Missile Agency at Huntsville, Ala., in 1956. Counterclockwise from the left: Maj. Gen. H. N. Toftoy, commanding general of ABMA, who organized Project Paperclip; Ernst Stuhlinger; Oberth; Wernher von Braun, Director, Development Operations Division; and Eberhard Rees, Deputy Director, Development Operations Division.*

Lieutenant Colonel G. A. Tokaty, one of his rocket experts. "We defeated the Nazi armies; we occupied Berlin and Peenemuende; but the Americans got the rocket engineers." [47] The Russians did obtain a windfall, however, in the form of hundreds of technicians and rank-and-file engineers, the Peenemuende laboratories and assembly plant, and lists of component suppliers. From those suppliers located in the Russian zone the Soviets secured enough parts to reactivate the manufacture of V–2s. The captured technicians and engineers were transported to the Soviet Union, where the Russian rocket specialists systematically drained them of the technical information they possessed but did not permit them to participate directly in the burgeoning postwar Soviet rocket development program.[48]

During the war Russian rocket developers, like their American counterparts, had concentrated on JATO and small bombardment rockets. "Backward though they were often said to be in matters of technology," observed James Phinney Baxter right after the war, "it was the Russians who in 1941 first employed rockets on a major scale. They achieved a notable success, and made more use of the rocket as a ground-to-ground weapon than any other combatant." [49] In the postwar years the Soviets quickly turned to the development of large liquid-propellant rockets. Lacking an armada of intercontinental bombers carrying atomic warheads, such as the United States possessed, they envisioned "trans-Atlantic rockets" as "an effective straightjacket for that noisy shopkeeper Harry Truman," to use Stalin's words.[50] Consequently the U.S.S.R. undertook to build a long-range military rocket years before nuclear weaponry actually became practicable for rockets; indeed, even before the Soviets had perfected an atomic device for delivery by aircraft.

The U.S.S.R. began exploration of the upper atmosphere with captured V–2s in the fall of 1947. Within two years, however, Soviet production was underway on a single-stage rocket called the T–1, an improved version of the V–2. The first rocket divisions of the Soviet Armed Forces were instituted in 1950 or 1951. Probably in 1954, development work began on a multistage rocket to be used both as a weapon and as a vehicle for space exploration. And in the spring of 1956 Communist Party Chairman Nikita Khrushchev warned that "soon" Russian rockets carrying thermonuclear warheads would be able to hit any target on Earth.[51]

## Postwar American Rocketry

Meanwhile the United States, convinced of the long-term superiority of her intercontinental bombers, pursued national security by means of airpower. The extremely heavy weight of atomic warheads meant that they would have to be delivered by large bombers, or by a much bigger rocket than anyone in the military was willing to ask Congress to fund. Despite the early postwar warnings of General Henry H. Arnold and others, for whom the V–2 experience was prophetic,

the Truman administration and Congress listened to conservative military men and civilian scientists who felt that until at least 1965 manned bombers, supplemented by air-breathing guided missiles evolving from the German V–1, should be the principal American "deterrent force." [52] Just after the war former NACA Chairman Bush, then Director of the Office of Scientific Research and Development, had expressed the prevailing mood in a much-quoted (and perhaps much-regretted) piece of testimony before a Congressional committee: "There has been a great deal said about a 3000-mile high-angle rocket. In my opinion, such a thing is impossible today and will be impossible for many years . . . . I wish the American public would leave that out of their thinking." [53]

The United States developed guided missiles for air-to-air, air-to-surface, and surface-to-air interception uses and as tactical surface-to-surface weapons. Rocket motors, using both liquid and solid fuels, gradually replaced jet propulsion systems, but short-range defensive missiles remained advanced enough for most tastes until the late 1950s.[54]

As for scientific research in the upper atmosphere, the backlog of V–2s put together by the United States Army from captured components would do in the early postwar years. From April 1946 to October 1951, 66 V–2s were fired at the Army's White Sands Proving Grounds, New Mexico, in the most extensive rocket and upper-atmospheric research program to that time. The Army Ordnance Department, the Air Force, the Air Force Cambridge Research Center, the General Electric Company, various scientific institutions, universities, and government agencies, and the Naval Research Laboratory participated in the White Sands V–2 program. Virtually all the rockets were heavily instrumented, and many of them carried plant life and animals. V–2s carried monkeys aloft on four occasions; telemetry data transmitted from the rockets showed no ill effects on the primates until each was killed in the crash. The most memorable launching at White Sands, however, came on February 24, 1949, when a V–2 boosted a WAC Corporal rocket developed by the Jet Propulsion Laboratory 244 miles into space and to a speed of 5510 miles per hour, the greatest altitude and velocity yet attained by a man-made object. A year and a half later, a V–2—WAC Corporal combination rose from Cape Canaveral, Florida, in the first launch at the Air Force's newly activated Long Range Proving Ground.[55]

By the late forties, with the supply of V–2s rapidly disappearing, work had begun on more reliable and efficient research rockets. The most durable of these indigenous projectiles proved to be the Aerobee, designed as a sounding rocket by the Applied Physics Laboratory of Johns Hopkins University and financed by the Office of Naval Research. With a peak altitude of about 80 miles, the Aerobee served as a reliable tool for upper-atmospheric research until the late 1950s.[56] The Naval Research Laboratory designed the Viking, a long, slim high-altitude sounding rocket, manufactured by the Glenn L. Martin Company of Baltimore. In August 1951 the Viking bettered its own altitude record for a single-stage rocket, reaching 136 miles from a White Sands launch. In the fifties, instrumenta-



*Launch of the record-setting U.S. Army–Jet Propulsion Laboratory Bumper WAC (V–2 first stage and WAC/Corporal second stage) from White Sands Proving Ground, N. Mex. The first Bumper-WAC launch occurred on May 13, 1948. On February 24, 1949, the two-stage rocket reached its record altitude of 244 miles and speed of 5150 miles per hour.*

tion carried in Aerobees and Vikings extended knowledge of the atmosphere to 150 miles, provided photographs of Earth's curvature and cloud cover, and gave some information on the Sun and cosmic radiation.[57]

In 1955 the Viking was chosen as the first stage and an improved Aerobee as the second stage for a new; three-stage rocket to be used in Project Vanguard, which was to orbit an instrumented research satellite as part of the American contribution to the International Geophysical Year. The decision to use the Viking and the "Aerobee-Hi" in this country's first effort to launch an unmanned scientific satellite illustrates the basic dichotomy in thought and practice governing postwar rocket development in the United States: After the expenditure of the V–2s, scientific activity should employ relatively inexpensive sounding rockets with small thrusts. Larger, higher-thrust, and more expensive rockets to be used as space launchers must await a specific military requirement. Such a policy meant that the Soviet Union, early fostering the ballistic missile as an intercontinental delivery system, might have a proven long-range rocket before the United States; the Soviets might also, if they chose, launch larger satellites sooner than this country.

By 1951, three sizable military rockets were under development in the United

States. One, an Air Force project for an intercontinental ramjet-booster rocket combination called the Navaho, took many twists and turns before ending in mid-1957. After 11 years and $680 million, the Air Force, lacking funds for further development, canceled the Navaho enterprise. Technologically, however, Navaho proved a worthwhile investment; its booster-engine configuration, for example, became the basic design later used in various rockets.[58] The two other rocket projects being financed by the military in the early fifties were ultimately successful, both as weapons systems and as space boosters.

### Redstone and Atlas

After the creation of a separate Air Force in 1947, the Army had continued rocket development, operating on the same assumption behind the German Army's research in the 1930s—that rocketry was basically an extension of artillery. In June 1950, Army Ordnance moved its team of 130 German rocket scientists and engineers from Fort Bliss at El Paso to the Army's Redstone Arsenal at Huntsville, Alabama, along with some 800 military and General Electric employees. Headed by Wernher von Braun, who later became chief of the Guided Missile Development Division at Redstone Arsenal, the Army group began design studies on a liquid-fueled battlefield missile called the Hermes C1, a modified V–2. Soon the Huntsville engineers changed the design of the Hermes, which had been planned for a 500-mile range, to a 200-mile rocket capable of high mobility for field deployment. The Rocketdyne Division of North American Aviation modified the Navaho booster engine for the new weapon, and in 1952 the Army bombardment rocket was officially named "Redstone."[59]

Always the favorite of the von Braun group working for the Army, the Redstone was a direct descendant of the V–2. The Redstone's liquid-fueled engine burned alcohol and liquid oxygen and produced about 75,000 pounds of thrust. Nearly 70 feet long and slightly under 6 feet in diameter, the battlefield missile had a speed at burnout, the point of propellant exhaustion, of 3800 miles per hour. For guidance it utilized an all-inertial system featuring a gyroscopically stabilized platform, computers, a programmed flight path taped into the rocket before launch, and the activation of the steering mechanism by signals in flight. For control during powered ascent the Redstone depended on tail fins with movable rudders and refractory carbon vanes mounted in the rocket exhaust. The prime contract for the manufacture of Redstone test rockets went to the Chrysler Corporation. In August 1953 a Redstone fabricated at the Huntsville arsenal made a partially successful maiden flight of only 8000 yards from the military's missile range at Cape Canaveral, Florida. During the next five years, 37 Redstones were fired to test structure, engine performance, guidance and control, tracking, and telemetry.[60]

The second successful military rocket being developed in 1951 was an Air Force project, the Atlas. The long history of the Atlas, the first American inter-

continental ballistic missile (ICBM),"[61] began early in 1946, when the Air Materiel Command of the Army Air Forces awarded a study contract for a long-range missile to Consolidated Vultee Aircraft Corporation (Convair), of San Diego. By mid-year a team of Convair engineers, headed by Karel J. Bossart, had completed a design for "a sort of Americanized V–2," called "HIROC," or Project MX–774. Bossart and associates proposed a technique basically new to American rocketry (although patented by Goddard and tried on some German V–2s)—controlling the rocket by swiveling the engines, using hydraulic actuators responding to commands from the autopilot and gyroscope. This technique was the precursor of the gimbaled engine method employed to control the Atlas and other later rockets. In 1947, the Truman administration and the equally economy-minded Republican 80th Congress confronted the Air Force with the choice of having funds slashed for its intercontinental manned bombers and interceptors or cutting back on some of its advanced weapons designs. Just as the first MX–774 test vehicle was nearing completion, the Air Force notified Convair that the project was canceled. The Convair engineers used the remainder of their contract funds for static firings at Point Loma, California, and for three partially successful test launches at White Sands, the last on December 2, 1948.[62]

From 1947 until early 1951 there was no American project for an intercontinental ballistic missile. The Soviet Union exploded her first atomic device in 1949, ending the United States' postwar monopoly on nuclear weapons. President Harry S. Truman quickly ordered the development of hydrogen-fusion warheads on a priority basis. The coming of the war in Korea the next year shook American self-confidence still further. The economy program instituted by Secretary of Defense Louis Johnson ended, and the military budget, including appropriations for weapons research, zoomed upward. The Army began its work leading to the Redstone, while the Air Force resumed its efforts to develop an intercontinental military rocket. In January 1951 the Air Materiel Command awarded Convair a new contract for Project MX–1593, to which Karel Bossart and his engineering group gave the name "Project Atlas."[63] Yet the pace of the military rocket program remained deliberate, its funding conservative.

A series of events beginning in late 1952 altered this cautious approach. On November 1, at Eniwetok Atoll in the Pacific, the Atomic Energy Commission detonated the world's first thermonuclear explosion, the harbinger of the hydrogen bomb. The device weighed about 60,000 pounds, certainly a much greater weight than was practicable for a ballistic missile payload. The next year, however, as a result of a recommendation by a Department of Defense study group, Trevor Gardner, assistant to the Secretary of the Air Force, set up a Strategic Missiles Evaluation Committee to investigate the status of Air Force long-range missiles. The committee, composed of nuclear scientists and missile experts, was headed by the famous mathematician John von Neumann. Specifically, Gardner asked the committee to make a prediction regarding weight as opposed to yield in nuclear payloads for some six or seven years hence. The

evaluation group, familiarly known as the "Teapot Committee," concluded that shortly it would be possible to build smaller, lighter, and more powerful hydrogen-fusion warheads. This in turn would make it possible to reduce the size of rocket nose cones and propellant loads and, with a vastly greater yield from the thermonuclear explosion, to eliminate the need for precise missile accuracy.[64] In February 1954 both the Strategic Missiles Evaluation Committee and the Rand Corporation, the Air Force-sponsored research agency, submitted formal reports predicting smaller nuclear warheads and urging that the Air Force give its highest priority to work on long-range ballistic missiles.

Between 1945 and 1953 the yield of heavy fission weapons had increased substantially from the 20-kiloton bomb dropped on Hiroshima. Now, according to the Air Force's scientific advisers, lighter, more compact, and much more powerful hydrogen warheads could soon be realized. These judgments "completely changed the picture regarding the ballistic missile," explained General Bernard A. Schriever, who later came to head the Air Force ballistic missile development program, "because from then on we could consider a relatively low weight package for payload purposes." [65] This was the fateful "thermonuclear breakthrough."

Late in March 1964 the Air Research and Development Command organized a special missile command agency, originally called the Western Development Division but renamed Air Force Ballistic Missile Division on June 1, 1957. Its first headquarters was in Inglewood, California; its first commander, Brigadier General Schriever. The Convair big rocket project gained new life in the winter of 1954–55, when the Western Development Division awarded its first long-term contract for fabrication of an ICBM. The awarding of the contract came in an atmosphere of mounting crisis and urgency. The Soviets had exploded their own thermonuclear device in 1953, and intelligence data from various sources indicated that they also were working on ICBMs to carry uranium and hydrogen warheads. Thus the Atlas project became a highest-priority "crash" program, with the Air Force and its contractors and subcontractors working against the fearsome possibility of thermonuclear blackmail.[66]

Rejecting the Army-arsenal concept, whereby research and development and some fabrication took place in Government facilities, the Air Force left the great bulk of the engineering task to Convair and its associate contractors.[67] For close technical and administrative direction the Air Force turned to the newly formed Ramo-Wooldridge Corporation, a private missile research firm, which established a subsidiary initially called the Guided Missiles Research Division, later Space Technology Laboratories (STL). With headquarters in Los Angeles, the firm was to oversee the systems engineering of the Air Force ICBM program.[68]

In November 1955, STL's directional responsibilities broadened to include work on a new Air Force rocket, the intermediate-range (1800-mile) Thor, hastily designed by the Douglas Aircraft Company to serve as a stopgap nuclear deterrent until the intercontinental Atlas became operational. At the same time








*Military missiles of the 1950s provided both the technology and the first-generation boosters for the nascent space program. The Air Force's Navaho (left) was a long-range cruise missile overtaken by the onrush of technology; though it was canceled as a project, it had pioneered the development of large rocket engines and guidance systems. The Atlas missile (center) had a hectic on-and-off career in the early 1950s but became the first operational ICBM and the major "large" boost vehicle for manned and unmanned space missions in the first decade of the space age. Thor (right), the sturdy, reliable baby of the Atlas technology, served an interim military role as an operational IRBM and a longer and more illustrious role as the workhorse booster of the first decade of payloads for military and nonmilitary space projects. Shown here with an Able second stage, it accepted a variety of second stages and payloads.*

Charles E. Wilson, Secretary of Defense in the Eisenhower administration, gave the Army and Navy joint responsibility for developing the Jupiter, another intermediate-range ballistic missile (IRBM), the engineering task for which went to the Army rocketmen at Redstone Arsenal. To expedite Jupiter development, the Army on February 1, 1956, established at Huntsville a Ballistic Missile Agency, to which Wernher von Braun and his Guided Missile Development Division were transferred. Later that year Wilson issued his controversial "roles and missions" memorandum, confirming Air Force jurisdiction over the operational deployment of intercontinental missiles, assigning to the Air Force sole jurisdiction over land-based intermediate-range weapons, restricting Army operations to weapons with ranges of up to 200 miles, and assigning ship-based IRBM's to the Navy. Partly as a result of this directive, but mainly because of the difficulty of handling liquid propellants at sea, the Navy withdrew from the Jupiter program and focused its interest on the Polaris, a solid-propellant rocket designed for launching from a submarine.[69]

As it developed after 1954, the Air Force ballistic missile development program, proceeding under the highest national priority and the pressure of Soviet missilery, featured a departure from customary progressive practice in weapons management. The label for the new, self-conscious management technique adopted by the Air Force Ballistic Missile Division–Space Technology Laboratories team was "concurrency." Translated simply, concurrency meant "the simultaneous completion of all necessary actions to produce and deploy a weapon system." [70] But in practice the management task—involving parallel advances in research, design, testing, and manufacture of vehicles and components, design and construction of test facilities, testing of components and systems, expansion and creation of industrial facilities, and the building of launch sites—seemed overwhelmingly complex. At the beginning of 1956 the job of contriving one ICBM, the Atlas, was complicated by the decision to begin work on the Thor and on the Titan I, a longer-range, higher-thrust, "second generation" ICBM.[71]

The basic problem areas in the development of the Atlas included structure, propulsion, guidance, and thermodynamics. Convair attacked the structural problem by coming up with an entirely different kind of airframe. The Atlas airframe principle, nicknamed the "gas bag," entailed using stainless steel sections thinner than paper as the structural material, with rigidity achieved through helium pressurization to a differential of between 25 and 60 pounds per square inch. The pressurized tank innovation led to a substantial reduction in the ratio between structure and total weight; the empty weight of the Atlas airframe was less than two percent of the propellant weight. Yet the Atlas, like an automobile tire or a football, could absorb very heavy structural loads.[72]

For the Atlas powerplant the Air Force contracted with the Rocketdyne Division of North American Aviation. The thermonuclear breakthrough meant that the original five-engine configuration planned for the Atlas could be scrapped in favor of a smaller, three-engine design. Thus Rocketdyne could contrive a unique

side-by-side arrangement for the two booster and one sustainer engines conceived by Convair, making it possible to fire simultaneously all three engines, plus the small vernier engines mounted on the airframe, at takeoff. The technique of igniting the boosters and sustainer on the ground gave the Atlas two distinct advantages: ignition of the second stage in the upper atmosphere was avoided, and firing the sustainer at takeoff meant that smaller engines could be used. The booster engines produced 154,000 pounds of thrust each; the sustainer engine, 57,000 pounds; and the two verniers, 1000 pounds each. The propellant for the boosters, sustainer, and verniers consisted of liquid oxygen and a hydrocarbon mixture called RP–1. The basic fuel and oxidizer were brought together by an intricate network of lines, valves, and often-troublesome turbopumps, which fed the propellant into the Atlas combustion chambers at a rate of about 1500 pounds per second. The thrust of the "one and one-half stage" Atlas powerplant, over 360,000 pounds, was equivalent to about five times the horsepower generated by the turbines of Hoover Dam or the pull of 1600 steam locomotives.[73]

The Atlas looked rather fat alongside the Army Redstone, the Thor, or the more powerful Titan. The length of the Atlas with its original Mark II blunt nose cone was nearly 76 feet; its diameter at the fuel-tank section was 10 feet, at its base, 16 feet. Its weight when fueled was around 260,000 pounds. Its speed at burnout was in the vicinity of 16,000 miles per hour, and it had an original design range of 6300 miles, later increased to 9000 miles.[74]

The prototype Atlas "A" had no operating guidance system. The Atlases "B" through "D" employed a radio-inertial guidance system, wherein transmitters on the rocket sensed aerodynamic forces acting on the missile and sent radio readings to a computer on the ground, which calculated the Atlas' position, speed, and direction. Radio signals were then sent to the rocket and fed through its inertial autopilot to gimbal the booster and sustainer engines and establish the Atlas' correct trajectory. After the jettisoning of the outboard booster engines, the sustainer carried the Atlas to the desired velocity before cutting off, while the vernier engines continued in operation to maintain precise direction and velocity. At vernier cutoff the missile began its unguided ballistic trajectory. A few moments later the nose cone separated from the rest of the rocket and continued on a high arc before plunging into the atmosphere. Radio-inertial guidance, the system used on the Atlas D and in Project Mercury, had the advantage of employing a ground computer that could be as big as desired, thus removing part of the nagging Atlas weight problem.[75]

By the mid-1950s the smaller thermonuclear warhead predicted by the Teapot Committee was imminent, so that the 360,000-pound thrust of the Atlas was plenty of energy to boost a payload of a ton and a half, over the 6300-mile range. But while nose-cone size ceased to be a problem, the dilemma of how to keep the ICBM's destructive package from burning up as it dropped into the ever-thickening atmosphere at 25 times the speed of sound remained. At such speeds even the thin atmosphere 60 to 80 miles up generates tremendous frictional heat, which

increases rapidly as an object penetrates the denser lower air. The temperature in front of the nose-cone surface ultimately may become hotter than the surface of the Sun. The atmospheric entry temperatures of the intermediate-range Thor, Jupiter, and Polaris were lower than those of the Atlas, but even for these smaller-thrust vehicles the matter of payload protection was acute.[76]

In the mid-fifties the "reentry problem" looked like the hardest puzzle to solve and the farthest from solution, not only for the missile experts but also for those who dreamed of sending a man into space and bringing him back. As von Kármán observed in his partially autobiographical history of aerodynamic thought, published in 1954:

> Any rocket returning from space travel enters the atmosphere with tremendous speed. At such speeds, probably even in the thinnest air, the surface would be heated beyond the temperature endurable by any known material. This problem of the temperature barrier is much more formidable than the problem of the sonic barrier.[77]

Years of concerted research by the military services, NACA, the Jet Propulsion Laboratory, and other organizations would be necessary before crews at Cape Canaveral, either preparing a missile shot or the launching of a manned spacecraft, could confidently expect to get their payload back through the atmosphere unharmed.

The American ballistic missile program of the 1950s produced some remarkable managerial and engineering achievements. Eventually the United States would deploy reliable ICBMs in larger numbers than the Soviet Union. Yet the fact remains that the Russians first developed such an awesome weapon, first tested it successfully, and first converted their larger ICBM for space uses.[78] Thus American missile developers fell short of what had to be their immediate goal—keeping ahead or at least abreast of the Soviets in advanced weaponry. Bureaucratic delays, proliferation of committees, divided responsibility, interservice rivalry, sacrificial attachment to a balanced budget, excessive waste and duplication, even for a "crash" program—these were some of the criticisms that missile contractors, military men, scientists, and knowledgeable politicians lodged against the Defense Department and the Truman and Eisenhower administrations. From 1953 to 1957, Secretaries of Defense Wilson and Neil H. McElroy presided over 11 major organizational changes pertaining directly to the missile program.[79] "It was just like putting a nickel in a slot machine," recalled J. H. Kindelberger, chairman of the board of North American Aviation, on the difficulty of getting a decision from the plethora of Pentagon committees. "You pull the handle and you get a lemon and you put another one in. You have to get three or four of them in a row and hold them there long enough for them to say 'Yes.' It takes a lot of nickels and a lot of time." [80] And even Schriever, certainly not one to be critical of the pace of missile development, admitted that "in retrospect you might say that we could have moved a little faster." [81]

## Sputniks and Soul-Searching

On August 26, 1957, Tass, the official Soviet news agency, announced that the U.S.S.R. had successfully launched over its full design range a "super long distance intercontinental multistage ballistic rocket," probably a vehicle employing the improved V–2, the T–1, as an upper stage and a booster rocket with a thrust of over 400,000 pounds the T–3.[82] In the furor in the West following the Russian announcement an American general allegedly exclaimed, "We captured the wrong Germans." [83]

Then, on October 4, the Soviets used apparently the same ICBM to blast into orbit the first artificial Earth satellite, a bundle of instruments weighing about 184 pounds called *Sputnik*, a combination of words meaning "fellow-traveler of the Earth." A month later Soviet scientists and rocket engineers sent into high elliptical orbit a heavily instrumented capsule, *Sputnik II*, weighing some 1120 pounds and carrying a dog named Laika.

The Russian ICBM shot in August had given new urgency to the missile competition and had prompted journalists to begin talking about the "missile gap." The Sputnik launches of the fall opened up a new phase of the Soviet-American technological and ideological struggle, and caused more chagrin, consternation, and indignant soul-searching in the United States than any episode since Pearl Harbor. Now there was a "space race" in addition to an "arms race," and it was manifest that at least for the time being there was a "space lag" to add to the ostensible missile gap.

After the first Sputnik went into orbit, President Dwight D. Eisenhower reminded the critics of his administration that, unlike ballistic missile development, "our satellite program has never been conducted as a race with other nations." [84] As far as the Soviet Union was concerned, however, there had been a satellite race for at least two and perhaps four years before the Sputniks. There was probably a Soviet parallel to the highly secret studies carried out in the immediate postwar years by the Rand Corporation for the Air Force and by the Navy Bureau of Aeronautics on the feasibility and military applicability of instrumented Earth satellites.[85] As late as 1952, however, Albert E. Lombard, scientific adviser in the Department of the Air Force, reported that "intelligence information on Soviet progress, although fragmentary, has given no indication on Soviet activity in this field." [86] Late the next year, President A. N. Nesmeyanov of the Soviet Academy of Sciences proclaimed that "Science has reached a state when it is feasible to send a stratoplane to the Moon, to create an artificial satellite of the Earth."[87] A torrent of Soviet books and articles on rockets, satellites, and interplanetary travel followed the Nesmeyanov statement.

In August 1955, a few days after the White House announced that the United States would launch a series of "small, unmanned, earth-circling satellites" during the 18-month International Geophysical Year, beginning July 1, 1957, Soviet aeronautical and astronautical expert Leonid Sedov remarked that the U.S.S.R.

would also send up satellites and that they would be larger than the announced American scientific payloads. Most Americans complacently tossed off Sedov's claim as another example of Russian braggadocio.[88] The formal announcement of the Russian space intentions came at the Barcelona Geophysical Year Conference in 1956. And in June 1957 the Soviet press advertised the radio frequency on which the first Russian satellite would transmit signals. By the end of the summer a few American Sovietologists were predicting freely that the U.S.S.R. would attempt a satellite launching soon, and they were somewhat surprised that the shot did not occur on September 17, 1957, the centennial of the birth of Tsiolkovsky.[89]

American embarrassment reached its apex and American technological prestige its nadir just over a month after *Sputnik II*. As the Senate Preparedness Subcommittee, headed by Lyndon B. Johnson, began an investigation of the nation's satellite and missile activities, Americans turned their attention to Cape Canaveral. There, according to White House Press Secretary James C. Hagerty, scientists and engineers from the Naval Research Laboratory and its industrial contractors would attempt to put in orbit a grapefruit-sized package of instruments as part of Project Vanguard, the American International Geophysical Year satellite effort. In reality the Vanguard group was planning only to use a test satellite in the first launch of all three active stages of the research rocket. To their dismay swarms of newsmen descended on Cape Canaveral to watch what the public regarded as this country's effort to get into the space race. On December 6, before a national television audience, the Vanguard first stage exploded and the rest of the rocket collapsed into the wet sand surrounding the launch stand.[90]

In the face of the fact that "they" orbited satellites before "we" did, together with the apparent complacency of official Washington, the Vanguard blowup took on disastrous proportions. McElroy had become Secretary of Defense on October 9, after Wilson's resignation. In mid-November he had authorized the Army Ballistic Missile Agency at Redstone Arsenal to revive "Project Orbiter." This was a scheme for using a Redstone with upper stages to orbit an instrumented satellite. It had been proposed jointly by the Office of Naval Research and the Army in 1954–1955 but overruled in the Defense Department in favor of the Naval Research Laboratory's Vanguard proposal, based on the Viking and Aerobee.[91] Now Wernher von Braun and company hurriedly converted their Jupiter C reentry test vehicle, an elongated Redstone topped by clustered solid-propellant upper stages developed by the Jet Propulsion Laboratory, into a satellite launcher.[92]

On January 31, 1958, just 84 days after McElroy's go-ahead signal, and carrying satellite instruments developed for Project Vanguard by University of Iowa physicist James A. Van Allen, a Jupiter C (renamed Juno I by the von Braun team) boosted into orbit *Explorer I*, the first American satellite. The total weight of the pencil-shaped payload was about 31 pounds, 18 pounds of which consisted of instruments. Following a high elliptical orbit, *Explorer I* transmitted data revealing the existence of a deep zone of radiation girdling



*Vanguard was the one nonmilitary launch vehicle of the early space program. More or less a descendant of the Viking rocket, the Vanguard rocket was important in its own right and for its legacy of contributions to NASA's Delta launch vehicle that would follow. Also the program built the Minitrack tracking network, which was to have a long, fruitful part to play in the space program.*

Earth, dubbed the "Van Allen belt." The following March 17, the much-maligned Vanguard finally accomplished its purpose, lifting a scientific payload weighing a little over 3 pounds into an orbit that was expected to keep the satellite up from 200 to 1000 years. *Vanguard I* proved what geophysicists had long suspected, that Earth is not a perfect sphere but is slightly pear-shaped, bulging in the aqueous southern hemisphere. *Explorer III,* with an instrumented weight of 18½ pounds, was fired into orbit by a Jupiter C nine days later. But in May a mammoth Soviet rocket launched a satellite with the then staggering weight of nearly 3000 pounds, some 56 times as heavy as the combined weight of the three American satellite payloads.[93]

Clearly, rockets that could accelerate such bulky unmanned satellites to orbital velocity could also send a man into space. And it seemed safe to assume that the Soviet politicians, scientists, and military leaders, capitalizing on their lead in propulsion systems, had precisely such a feat in mind. When the one-and-one-half-ton *Sputnik III* shot into orbit, the Atlas, star of the American missile drive, viewed not only as the preeminent weapon of the next decade but also as a highly promising space rocket, was still in its qualification flight program. Plagued by

turbopump problems and fuel sloshing, so far it had made only two successful test flights, out of four attempts.[94]

Yet American military planners remained confident that the Atlas finally would become a reliable missile. It must if the United States was not to fall perilously behind in the frenzied competition with the Soviets, if the missile gap was not to widen. And what of the advocates of manned space flight, the ambitious individuals on the fringes of the scientific community, NACA, and the military services—people who saw the Atlas, not the frail Vanguard or the Jupiter C, as holding the key to space? They also kept their hopes high.

# III

# Exploring the Human Factor

(1948–1958)

THE development of the large liquid-fueled rocket made the dazzling prospect of manned flight beyond Earth's atmosphere and into the vacuum of space increasingly feasible from the standpoint of propulsion. By 1950, however, only instrumented sounding rockets, fired to ever higher altitudes in both the United States and the Soviet Union, had reached into space before falling earthward. Although a number of these experimental shots carried living organisms—everything from fungus spores to monkeys in the United States, mainly dogs in the U.S.S.R.—the data acquired from telemetry and from occasional recovery of rocket nose cones had not shown conclusively how long organisms could live in space, or indeed whether man could survive at all outside the protective confines of his atmosphere. Scientists still were hesitant to predict how a human being would behave under conditions to be encountered in space flight. Thus while space flight became technologically practicable, physiologically and psychologically it remained an enigma.

In the early 1950s an acceleration of efforts in upper-atmospheric and space medical research accompanied the quickened pace of rocket development in this country and in the Soviet Union. During the next few years medical specialists, profiting from substantial progress in telemetering clinical data, learned a great deal about what a man could expect when he went into the forbidding arena of space.[1] Much of the confidence with which the engineers of Project Mercury in 1958 approached the job of putting a man into orbit and recovering him stemmed from the findings of hundreds of studies made in previous years on the human factors in space flight.

Since the National Advisory Committee for Aeronautics was interested almost exclusively in the technology of flight, research in the medical problems of space flight, like aviation medicine in previous decades, was the province primarily of the military services and of some civilian research organizations receiving funds from the military. Of the three services, the United States Air Force, rich in background in aeromedical research and assuming that space medicine was but an

extension of aviation medicine, undertook most of the early inquiry into the psychophysiological problems of extra-atmospheric flight.

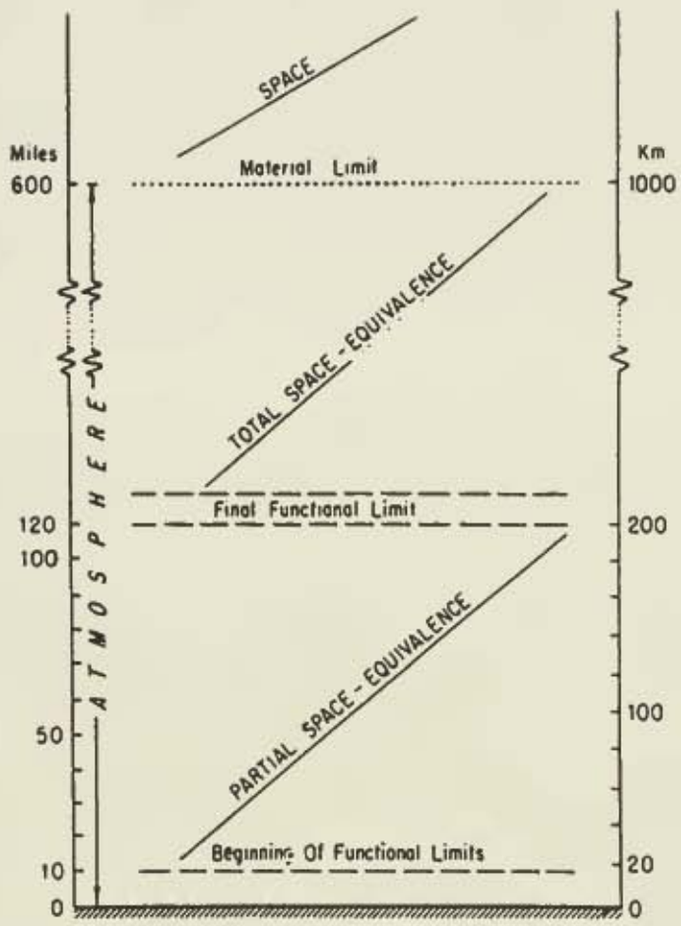
## Beginnings of Space Medicine

After the Second World War the Air Force acquired the talents of a number of scientists who had done much remarkable research on the medical aspects of high-speed, high-altitude airplane flight for Germany's Luftwaffe.[2] Most of these German physicians, physiologists, and psychologists were brought to the expanding Aeromedical Laboratory at Wright-Patterson Air Force Base, near Dayton, Ohio. Six of the more prominent German aeromedical specialists, Hubertus Strughold, Hans-Georg Clamann, Konrad Buettner, Siegfried J. Gerathewohl, and the brothers Fritz and Heinz Haber, were assigned as research physicians to the Air Force School of Aviation Medicine, located on the scrub prairies of south central Texas at Randolph Air Force Base, outside San Antonio. The commandant of the school was Colonel Harry G. Armstrong, author of the classic text in aviation medicine.[3] While heavily instrumented V–2s lumbered upward from White Sands and plastic research balloons lifted seeds, mice, hamsters, fruit flies, and other specimens into the upper atmosphere, Armstrong and his associates were already considering the medical implications of flight by man into the hostile space environment.

In November 1948, Armstrong organized at Randolph a panel discussion on the "Aeromedical Problems of Space Travel." Featuring papers by Strughold and Heinz Haber and commentary by six well-known scientists from universities and the military, the symposium perhaps marked the beginning of formal, academic inquiry into the medical hazards of extra-atmospheric flight. Before this epochal gathering ended, Strughold had resolved the contradiction inherent in the title of the symposium by emphatically using the term "space medicine." [4]

The following February, Armstrong set up the world's first Department of Space Medicine, headed by Strughold and including the Habers and Konrad Buettner.[5] In November 1951, at San Antonio, the School of Aviation Medicine and the privately financed Lovelace Foundation for Medical Research at Albuquerque, New Mexico, sponsored a symposium discreetly entitled "Physics and Medicine of the Upper Atmosphere." It was still not respectable to speak plainly of space flight within the Air Force, which only that year had cautiously reactivated its intercontinental ballistic missile project and remained sensitive to "Buck Rogers" epithets from members of Congress and the taxpaying public. A good portion of the material presented by the 44 speakers at the 1951 symposium, however, covered the nature of space, the mechanics of space flight, and the medical difficulties of sending a man beyond the sensible and breathable atmosphere.[6]

It was at this meeting that Strughold, later to acquire a reputation as the "father of space medicine," put forth what is perhaps his most notable contribution—the concept of "aeropause," a region of "space-equivalent conditions" or




*An important bridge from aviation medicine to space medicine was this chart by Hubertus Strughold in 1951. It related altitudes at which human functional borders occur with the altitudes at which the various physical characteristics of space occur.*

"atmospheric space equivalence." Strughold pointed out that while many astronomers, astrophysicists, and meteorologists set the boundary between the atmosphere and space at about 600 miles from Earth, the biological conditions of space begin much lower, at about 50,000 feet. Anoxia is encountered at 50,000 feet, the boiling point of body fluids at 63,000 feet, the necessity for carrying all respiratory oxygen within a manned compartment at 80,000 feet, meteoroids at 75 miles, and the darkness of the space "void" at 100 miles. Above 100 miles the atmosphere is imperceptible to the flyer. "What we call upper atmosphere in the physical sense," said Strughold, "must be considered—in terms of biology—as space in its total form." Hence manned ballistic or orbital flight at an altitude of 100 miles would be, for all practical purposes, space flight.[7]

The rocket-powered research airplanes of the postwar years, beginning with the X–1, the first manned vehicle to surpass the speed of sound, took American test pilots well into the region of space equivalence. On August 26, 1954, when Major Arthur Murray of the Air Force pushed the Bell X–1A to an altitude of

90,000 feet, he was above 90 percent of the sensible atmosphere. Two years later, in the more powerful Bell X–2, Air Force Captain Iven Kincheloe climbed to 126,000 feet, "a space-equivalent flight to a very high degree." [8] The X–15, still on the drawing boards in the mid-fifties, was being designed to rocket its pilot to an altitude of 50 miles at nearly seven times the speed of sound. And human-factors research in the X–15 project, involving the development and testing of a new full-pressure flying suit, centrifuge conditioning to high acceleration forces, and telemetering a wide range of physiological data in flight, would contribute substantially to medical planning for space travel.[9]

## Zero G

At peak speed and altitude an X–15 flight was supposed to afford about five minutes of "weightlessness" or "zero g." This is the effect created when a vehicle is balanced between centrifugal and centripetal forces—when the gravitational pull of Earth and other heavenly bodies is exactly balanced by the inertial character of the vehicle's motion. Weightlessness is undoubtedly the most fascinating medical characteristic of space flight, and it aroused the most speculation among aviation physicians in the late forties and early fifties. To be sure, approximations of zero g were not totally new human experiences; a common illustration of the sensation is the sudden partial lightening of the body in a rapidly descending elevator. But the necessity to function at zero g—to eat and drink, to eliminate body wastes, to operate the spacecraft controls—was a new requirement and presented new problems for the aeromedical teams.

Flight physicians were almost unanimous in expressing forebodings about the effect of weightlessness on man's physical and mental performance. Some feared that the body organs depended on sustained gravity and would not function if deprived of the customary gravitational force. Others worried over the combined effects of acceleration, weightlessness, and the heavy deceleration during atmospheric entry. Still other experts were concerned especially about perception and equilibrium. For example, Heinz Haber and Otto Gauer, another émigré German physician who joined the Air Force aeromedical program, noted that the brain receives signals on the position, direction, and support of the body from four mechanisms—pressure on the nerves and organs, muscle tone, posture, and the labyrinth of the inner ear. They theorized that these four mechanisms might give conflicting signals in the weightless state and that such disturbances "may deeply affect the autonomic nervous functions and ultimately produce a very severe sensation of succumbence associated with an absolute incapacity to act." [10]

The basic difficulty retarding the study of weightlessness was the impossibility of duplicating the exact condition on Earth. The X–15, considered by many in the mid-fifties to be the penultimate step to manned orbital flight, progressed slowly and would fly too late to shed much light on the problem of zero g for Project Mercury. By the fall of 1958, however, when the newly formed National

Aeronautics and Space Administration undertook to orbit a manned satellite, American aeromedical researchers had been studying the gravity-free condition intensively for some eight years.

The best but most expensive device for zero-g experimentation was the sounding rocket. For several years, beginning with the V–2 firings from White Sands, parachutes for nose cones containing rocket-launched animals invariably failed to open and the subjects were killed on impact. The first successful recovery came in September 1951, when an instrumented monkey and 11 mice survived an Aerobee launch to 236,000 feet from Holloman Air Force Base, New Mexico. The last of three Aerobee shots at Holloman, in May 1952, like the previous experiments, carried a camera on board to photograph two mice and two monkeys under acceleration, weightlessness, and deceleration. An Air Force aeromedical team, headed by James P. Henry, a physician who later would direct the Mercury animal program, and young Captain David G. Simons, found no adverse effects on the animals.[11]

For the next six years the priority military ballistic missile program almost monopolized rocket development in the United States. Medical experimentation employing live test subjects launched to high altitudes by rockets came to a virtual standstill. By contrast, during the same period from 1952 to 1957, researchers in the Soviet Union carried out numerous animal rocket flights, with dogs of the Pavlovian sort being their favorite passengers. By late 1957, when the Soviets sent the dog Laika into orbit aboard *Sputnik II*, the peak altitude of their vertical launches of animals was nearly 300 miles, and the Russian scientists had perfected a technique for catapulting animals from nose cones and recovering them with parachutes. Apparently the Russians also were able to measure a wider range of physiological reactions than their American counterparts.[12]

During the six-year hiatus in animal rocket experimentation in this country, investigators had to resort to the aircraft, "the oldest aeromedical laboratory," for studying the weightless phenomenon.[13] In 1950, Fritz and Heinz Haber, of the Air Force School of Aviation Medicine, had considered various ways of simulating zero g for medical experiments. Discarding the free fall and the elevator ride, the Habers concluded that the best technique involved an airplane flight along a vertical parabola, or "Keplerian trajectory." If properly executed, such a maneuver could provide as much as 35 seconds of zero g and a somewhat longer period of subgravity, a condition wherein the body is under only partial gravitational stress.[14] During the summer and fall of 1951 test pilots A. Scott Crossfield of NACA and Charles E. Yeager of the Air Force tried out the technique, flying a number of Keplerian trajectories in jet interceptors. Up to 20 seconds of weightlessness resulted from some of these flights. Crossfield reported initial "befuddlement" during zero g but no serious loss of muscle coordination, while Yeager described a sensation of falling and in one instance of spinning and feeling "lost in space." The latter sensation the physicians and psychologists called "disorientation."[15]

The Habers' technique and these early experiments with it represented a promising beginning, but as one Air Force aeromedical specialist pointed out, "The results of these flights were inconclusive in many respects." [16] An enormous amount of work remained before students of weightlessness could do much generalizing about this greatest anomaly of space flight.

In 1953 a small group comprising the Space Biology Branch of the Aeromedical Field Laboratory at Holloman Air Force Base inaugurated an ambitious program of parabolic flights to continue the investigations of weightless flight that had halted with the termination of the Aerobee animal launches in the spring of 1952. Supervised by Major David G. Simons, a physician who acted as test subject on many occasions, the Holloman studies for two years utilized T–33 and F–89 jet aircraft. Late in 1955, after Captain Grover J. D. Schock came to the field laboratory as task scientist, the standard tool for zero g research became the F–94C, which offered a longer parabola than other aircraft and thus a longer period of weightlessness. In the summer of 1958 the Air Force canceled all zero-g research at Holloman, and the coterie of scientists broke up. Colonel John P. Stapp, head of the field laboratory, and Simons went elsewhere, while Schock turned his attention to other research projects.[17]

For three years before the termination of the Holloman flight program, students of zero g at the School of Aviation Medicine had duplicated and even surpassed the investigations being carried out in New Mexico. Although sponsored by the Department of Space Medicine, the program carried out at Randolph Air Force Base was actually directed by Siegfried Gerathewohl, who was not a member of the department. Gerathewohl and his colleagues began their studies with the T–33 jet trainer, but like their counterparts in New Mexico, they soon turned to the superior F–94C. Major Herbert D. Stallings, a Randolph physician, estimated that by April 1958 he had flown more than 4000 zero-g trajectories and compiled about 37 hours of weightless flight.[18]

Gerathewohl, Simons, Schock, and the other scientists at Randolph and Holloman tried to get as great a variety of information as possible during the 30 to 40 seconds of weightlessness and subgravity produced by the F–94C flights. They carried out numerous eye-hand coordination tests, for example, wherein a subject tried to make crosses in a pattern or hit a target with a metal stylus. Subjects usually missed their mark in the first moments of zero g or subgravity, but most of them improved their performance with their cumulative experience. The Air Force scientists also studied eating and drinking, bladder function, and disorientation after awakening during weightlessness; the functions at zero g of various animals, especially cats, whose vestibular organs had been removed; and the phenomenon called the "oculo-agravic illusion," wherein luminous objects seen in the dark appear to move upward during weightlessness.[19]

At the Wright Air Development Center, in Ohio, a team of researchers headed by Major Edward L. Brown picked up the experimental program discontinued at Holloman in mid-1958, except that they used the relatively slow, propeller-driven

C–131 transport in their studies. A parabola in a C–131 gave only 10 to 15 seconds of weightlessness, but the spacious interior of the cargo carrier made it possible to observe the reactions of several subjects simultaneously, including their coordination and locomotion and even their ability to walk along the ceiling while wearing shoes with magnetic soles.[20]

In general the aeromedical specialists at Randolph, Holloman, and Wright-Patterson—as well as those in more modest programs at the Navy School of Aviation Medicine, Pensacola, Florida, and at the NACA Lewis Flight Propulsion Laboratory in Cleveland—found that the principal problems of weightless flight seemed solvable. Eating and drinking at zero g were not troublesome when squeeze bottles and tubes were used, and urination presented no real difficulty. Some subjects suffered nausea, disorientation, loss of coordination, and other disturbances, but the majority reported that after they adjusted to the condition they found it "pleasant" and had a feeling of "well-being." [21] As early as 1955, Simons concluded that weightlessness produced no abnormalities with regard to heart rate and arterial and venous blood pressure, while Henry, Simons' colleague in the Aerobee animal experiments, prophesied, "In the skilled pilot weightlessness will probably have very little significance." [22] And in 1959, about a year after Project Mercury got underway, Gerathewohl remarked that "the majority of flying personnel enjoy the exposure to the subgravity state in our controlled experiments. We have reason to believe that even longer periods of absolute weightlessness can be tolerated if the crew is properly conditioned and equipped." [23]

## Multiple G

Another problem perplexing aeromedical experts as the era of space flight neared was the effect on the human body of the heavy acceleration and deceleration forces, called "g loads," building up during rocket-propelled flights into space at speeds far greater than those yet experienced by man. Many fighter pilots in the Second World War had suffered momentary pain and blurred vision during "redout," when blood pooled in the head and eyes during an outside loop, or "blackout," when the heart suddenly could not pump enough blood to the head region as an airplane pulled out of a steep dive. Acceleration of a vehicle into space and the deceleration accompanying its return to the atmosphere would subject a man to g loads several times the normal accelerative force of gravity. In other words, for parts of a space mission a man would come to "weigh" several times what he normally did on Earth; a severe strain would be imposed on his body organs.

At the Aeromedical Field Laboratory in New Mexico, Harald J. von Beckh, a physician who had immigrated from Germany by way of the Instituto Nacional de Medicina Aeronáutica in Buenos Aires, was especially concerned about the ability of a space traveler to tolerate the high deceleration forces of atmospheric entry after several hours of weightlessness. In the last few months before such

research ended at Holloman, von Beckh inquired into the relationship between zero g and the multiplication of g. He added a steep downward spiral to the level, weightless portion of the Keplerian trajectory in order to impose heavy g loads on a test subject immediately after a half minute or so of weightlessness. After a number of these parabolic-spiral flights, he reported pessimistically, "Alternation of weightlessness and acceleration results in a decrease of acceleration tolerance and of the efficiency of physiologic recovery mechanisms . . . Because there is a decreased acceleration tolerance," he warned, "every effort must be made to reduce G loads to a minimum." [24]

Throughout the 1950s a substantial number of aeromedical experts concerned themselves with acceleration-deceleration loads per se, not necessarily in connection with the gravity-free state. Research on g forces reached back for decades, to the primitive period of aviation medicine. The state of knowledge with regard to the physiology of acceleration-deceleration was still hazy and fluid in the early fifties, although for at least 25 years aviation physicians in Europe and the United States had been studying blackout, redout, impact forces, and other effects of high g in aircraft.[25] The V–2 and Aerobee animal rocket shots also had added to research data on the problem. But until the X–15 was ready, researchers had about exhausted the airplane as a tool for studying g loads, and from 1952 to 1958 experimentation with animal-carrying rockets was suspended in the United States. Consequently American scientists had to turn to two devices on the ground—the rocket-powered impact sled, used for studying the immediate onset of g loads, and the centrifuge, where the slower buildup of g could be simulated—to enlarge what they knew about the limits of human endurance of heavy acceleration and deceleration.

On December 10, 1954, Lieutenant Colonel John P. Stapp of the Aeromedical Field Laboratory gave an amazing demonstration of a man's ability to withstand immediate impact forces. Stapp rode a rocket-driven impact sled on the 3550-foot Holloman research track to a velocity of 937 feet per second and received an impact force of 35 to 40 g for a fraction of a second as the sled slammed to a halt in a water trough.[26] In February 1957 a chimpanzee rocketed down the track, now 5000 feet long, braked to a stop, and survived a load of some 247 g for a millisecond, with a rate of onset of 16,000 g per second. And 15 months later, on the 120-foot "daisy track" at Holloman, Captain Eli L. Beeding, seated upright and facing backward, experienced the highest deceleration peak yet recorded on a human being—83 g for .04 of a second, with 3826 g per second as the calculated rate of onset. Afterward Beeding, recovering from shock and various minor injuries, judged that 83 g represented about the limit of human tolerance for deceleration.[27]

Such studies of deceleration were not directed primarily toward space missions but rather toward the problem of survival after ejection from or crashes in high-performance aircraft. The Holloman sled runs of the fifties, however, did broaden considerably the available data on the absolute limits of man's ability

to endure multiples of g. And, perhaps more important, the New Mexico experiments in biodynamics were directly applicable to the problem of high g forces resulting from the uncushioned impact of a spacecraft on water or land. Stapp reasoned that a properly restrained, aft-facing human being could withstand a land impact of some 80 knots (135 feet per second) in a spacecraft if the g forces were applied transversely, or through the body, and if the spacecraft did not collapse on him.[28]

The centrifuge, the other laboratory tool used by students of acceleration-deceleration patterns, became increasingly useful in the fifties. The basic feature of the centrifuge was a large mechanical arm with a man-carrying gondola or platform mounted on the end, within which a test subject would be rotated at high angular velocities. Centrifuge experiments had more immediate pertinence to space medicine than impact sled tests, because on the "wheel" investigators could duplicate the relatively gradual buildup of g forces encountered during the launch and reentry portions of ballistic, orbital, or interplanetary flight. In the fifties, centrifuges existed at several places in the United States. The best-known and most used were at the Navy's Aviation Medical Acceleration Laboratory, Johnsville, Pennsylvania, and at the Aeromedical Laboratory at Wright-Patterson Air Force Base. During the decade, researchers at Johnsville, Wright-Patterson, and elsewhere simulated a wide variety of acceleration and deceleration profiles, using an almost equally wide variety of body positions and support systems, to compile an impressive quantity of data on the reactions of potential space pilots to heavy g forces.[29]

Just after the Second World War, Otto Gauer and Heinz Haber, who had conducted centrifuge experiments for the German Air Force, proposed a series of acceleration patterns, ranging from 3 g for 9½ minutes to 10 g for 2 minutes, all of which would be tolerable for a space pilot.[30] Then, in 1952, E. R. Ballinger, leader of the research program at Wright-Patterson, conducted one of the earliest series of centrifuge tests directed expressly toward the problem of g forces in space flight. Ballinger found that 3 g applied transversely would be the ideal takeoff pattern from the physiological standpoint, but he realized that the rocket burning time and velocity for such a pattern would be insufficient to propel a spacecraft out of the atmosphere. Consequently he and his associates subjected men to gradually increasing g loads, building to peaks of 10 g for something over two minutes. Chest pain, shortness of breath, and occasional loss of consciousness were the symptoms of those subjected to the higher g loads. The tests led Ballinger to the conclusion that 8 g represented the acceleration safety limit for a space passenger.[31]

Data gained from the first Soviet and American instrumented satellites of late 1957 and early 1958 showed that the atmosphere reached considerably farther out than scientists previously had realized. Until these disclosures aeromedical experts had assumed that the deceleration, or backward acceleration, forces of reentry, producing what was graphically described as an "eyeballs out" sensation,

would be much greater than the acceleration during the ascent, or "eyeballs in," phase of the mission. Proceeding on this assumption, a team of physiologists from the Army, Navy, and Air Force had used the 50-foot centrifuge at the Navy's Johnsville installation to study the anticipated high reentry g buildup, exposing five chimpanzees to a peak of 40 g for one minute. Post-run examinations of the primates showed internal injuries, including heart malfunctions. It appeared that prolonged subjection to high g might be severely injurious or perhaps even fatal to a man.[32]

The tests conducted by Ballinger at Wright-Patterson and the interservice experiments with the chimpanzees on the Navy centrifuge featured frontward (eyeballs-in) application of g loads during the launch profile, backward application (eyeballs-out) during the reentry simulation, and the use of rather elaborate restraint straps and basic aircraft bucket seats as a support system. The problem of determining optimum body position and support was vigorously attacked by biodynamicists during 1957 and 1958. A series of especially careful studies on the Wright Air Development Center centrifuge indicated that when the subject was positioned so that the g forces were applied transversely and backward to the center of rotation, breathing became easier. Acceleration-deceleration patterns of 12 g for 4 seconds, 8 g for 41 seconds, and 5 g for 2 minutes were endured without great difficulty by practically all the volunteer subjects, some having even higher tolerance limits. Results of runs on the Johnsville centrifuge with the subjects in an aft-facing position for both acceleration and deceleration patterns also appeared favorable.[33]

The students of g forces tried various support devices in the late fifties in their search for ways to increase human tolerance to acceleration and deceleration loads. One specialist in the Wright-Patterson centrifuge group came up with a suit of interwoven nylon and cotton material, reinforced by nylon belting, and attached to the pilot seat at six places to absorb the g loads and distribute them more evenly over the entire body. Later, Wright-Patterson scientists using a nylon netting arrangement in conjunction with a contour couch were able to expose several men to a peak of 16.5 g for several seconds without any discoverable adverse effects. Other Air Force specialists experimented with subjects partially enclosed in a "rigid envelope," actually a plaster cast, as protection against both g-load buildup and impact forces. And von Beckh, whose concern with the weightlessness-deceleration puzzle led him to experiment with anti-g techniques, developed a device called "multi-directional g protection," a compartment that turned automatically to ensure that the g forces were always applied transversely on its occupant. Von Beckh's invention was used to protect a rat that went along on Beeding's record sled run in 1958, and a modified compartment carried three mice on a Thor-Able rocket launch the same year. Results in both experiments were encouraging.[34]

Navy scientists were especially interested in water immersion as a means of minimizing g loads. Researchers in Germany, Canada, and the United States

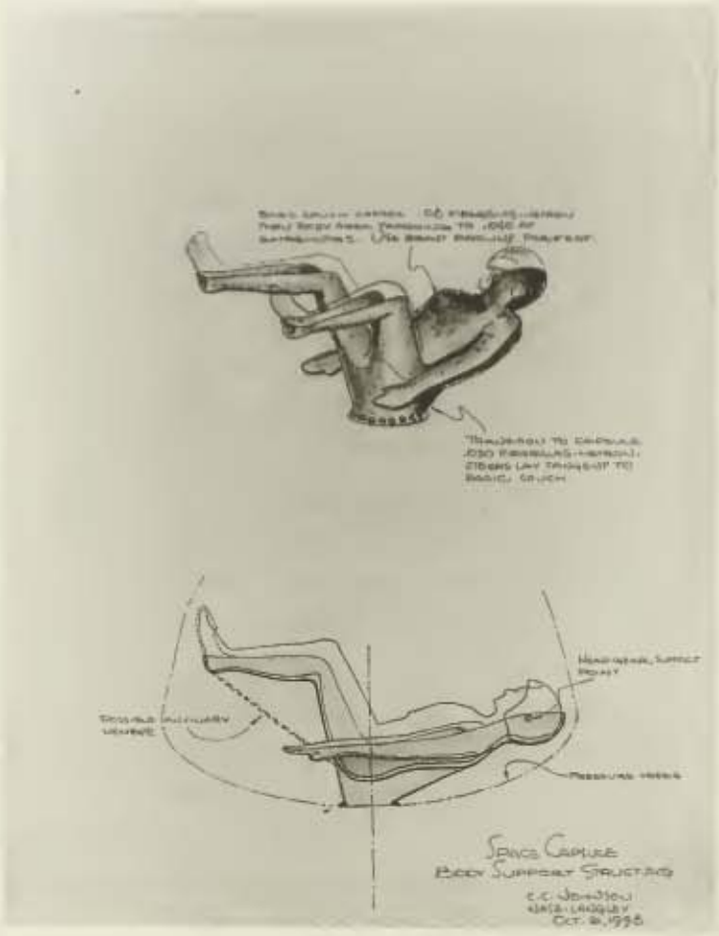
had experimented with water-lined flying suits and submersion in water tanks, beginning in the 1930s. Specialists had carried out sporadic biodynamic tests with immersed rabbits and mice in the late forties at the Navy School of Aviation Medicine and, after the giant centrifuge began operation in 1952, in Johnsville.[35]

In 1956, R. Flanagan Gray, a physician at the Johnsville laboratory, designed an aluminum centrifuge capsule that could be filled with water and was large enough to hold a man. After some initial troubles installing the contraption on the centrifuge and perfecting an emergency automatic flushing mechanism, the "Iron Maiden," as it was rather inaccurately nicknamed, went into use. In March 1958, Gray, immersed to his ribs in a bathtub-like device developed at the Mayo Clinic during the Second World War, had endured 16 g of headward (head to feet) acceleration. Then, the next year, Gray enclosed himself in the Iron Maiden and, positioned backward to the center of rotation and immersed in water above the top of his head, held his breath during the 25-second pattern to withstand a peak of 31 g transverse acceleration for five seconds. This performance with the water-filled aluminum capsule established a new record for tolerance of centrifuge g loads.[36]

Nylon netting, multidirectional positioning, and water immersion were all promising methods for combating g forces and expanding human endurance limits. But netting had a troublesome tendency to bounce the subject forward as the g forces diminished, while directional positioning and water-immersion apparatus required more space and weight than would be available in a small, relatively light spacecraft.[37] And considering the thrust limitations of the Thor, the Atlas, or the somewhat larger Titan ICBM, a small spacecraft was the only feasible design for an American manned satellite in 1958.

At the inception of the NASA manned satellite project, in the fall of 1958, the apparent solution to the problem of body support was an anti-g contrivance developed not by biodynamicists but by a group of practicing aerodynamicists in NACA's Pilotless Aircraft Research Division, part of the Langley Aeronautical Laboratory in Virginia. Maxime A. Faget, William M. Bland, Jr., Jack C. Heberlig, and a few other NACA engineers had designed an extremely strong and lightweight couch, made of fiber glass, which could be contoured to fit the body dimensions of a particular man. In the spring of 1958, technicians and shopmen at Langley molded the first of a series of test-model contour couches. The following July a group from Langley went to the Aviation Medical Acceleration Laboratory at Johnsville to try out their couch on the Navy's big centrifuge.[38]

The Navy biodynamicists and the NACA engineers experimented with the couch and various body positions in an effort to amplify a g-load tolerance. The couch made at Langley had been molded to fit the physical dimensions of Robert A. Champine, one of the foremost NACA test pilots. Champine rode the Johnsville centrifuge to a peak of 12 g on July 29, then departed for a conference on the Pacific Coast. The next day Navy Lieutenant Carter C. Collins volunteered to test the couch. Since his frame was smaller than Champine's, the Johnsville



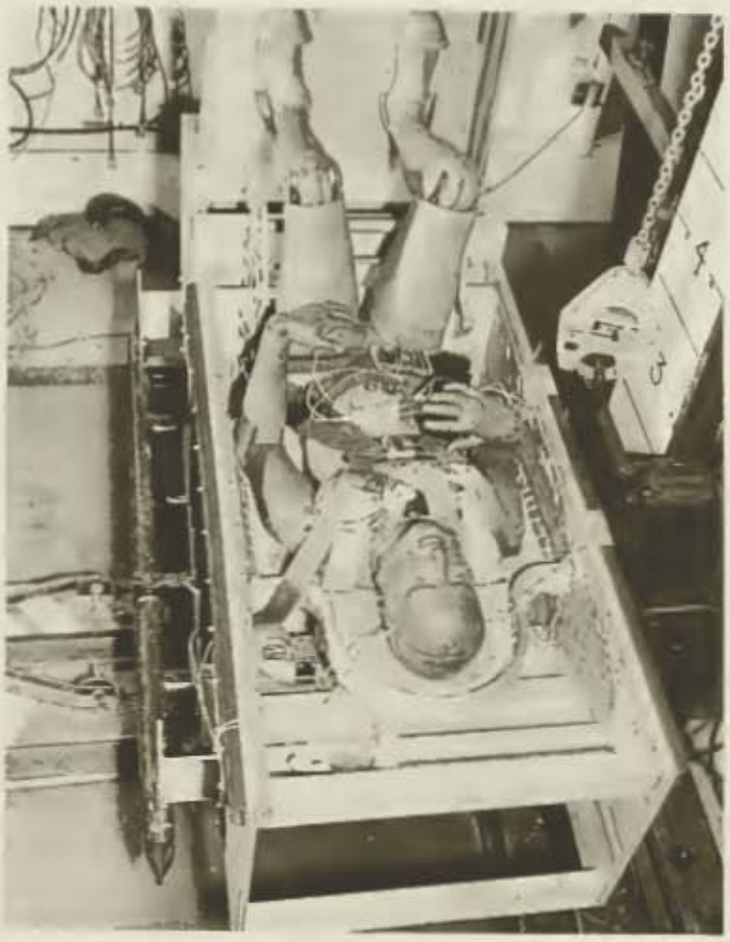

## Mercury

*One of the most critical design and feasibility problems in the early days of Mercury was whether the astronaut could be safely restrained and supported through the succession of vibration levels, g forces, weightlessness, and more g forces that would occur in space flight. Langley laboratory engineers conceived the contour couch (left) in 1958, and refined it enough to try a model (below) in 1959.*



## Couch

*After the couch concept had been devised, there was the problem of a system to provide the contradictory combination of restraint, cushioning, and support. An early couch of nylon netting (right) was ruled out because it bounced the occupant forward as g forces diminished. The final choice was fiber glass cast to the contour of each astronaut (below) and equipped with restraining straps.*





experts had to pack foam-rubber padding into the recesses of the fiber-glass bed. Collins then climbed into the centrifuge gondola and seated himself in the couch, the back angle of which was set forward 10 degrees. The 4000-horsepower centrifuge motor whirled the gondola progressively faster. On the first run the loads reached a peak of 12 g. Five more runs pushed the peak to 18 g. Then, on the sixth try, using a grunting technique to avoid blackout and chest pains, Collins withstood a peak of 20.7 g, applied transversely for a duration of six seconds. Later that day, Gray, inventor of the Iron Maiden, rode the centrifuge with the contour couch and also endured a 20-g peak. The acceleration patterns to which Collins and Gray were exposed corresponded to a reentry angle of 7.5 degrees. At that time the optimum reentry angle being considered for a manned satellite, 1.5 degrees, theoretically would expose the spacecraft passenger to only 9 g.[39]

The NACA engineers, already working overtime on designs for a manned orbital capsule, were elated. It seemed that they finally had an effective anti-g device that was small enough and light enough to fit into a one-ton ballistic capsule they had in mind for the initial manned space venture.[40] They had, in fact, made a major contribution to the protection of a space rider from sustained high g forces, although they did not fully realize as yet that body angles were more significant features of the couch than its contoured support.

The procedure ultimately used for protecting the Mercury astronauts from the g loads of acceleration to orbital velocity and deceleration during reentry represented a combination of the advantages gained from many experiments by military and other specialists in flight physiology, as well as from the ingenuity of the aeronautical engineers in NACA and NASA. Although the idea of using a hammock either for the basic support or in combination with the contour couch was perennially attractive to the human-factors experts in Project Mercury, all Mercury astronauts sat in essentially the same couch designed by Faget and his coworkers in the spring of 1958. But added to this basic technique were restraining straps, a semi-supine posture, frontward application of acceleration loads, and the reversal of the spacecraft attitude during orbit to permit frontward imposition of reentry loads as well. The final elements in the NACA–NASA campaign to minimize the effects of insertion-reentry g buildups was the use as astronauts of experienced test pilots provided by the military services. During the centrifuge experiments of the fifties such men had consistently proved capable of withstanding higher g forces than nonpilots.

### Environmental Control

High-altitude atmospheric flight had necessitated much work related to two serious physiological problems of space flight—air supply and the pressure required for breathing in space. Research on these problems in the United States stretched back to 1918, when the Army began operation of a decompression chamber at Hazelhurst Field, Long Island. In the early 1930s the civilian aviator

Wiley Post wore a pressure suit, looking like a deep-sea diver's outfit, for high-altitude flying. By the early fifties the typical jet pilot breathed pure oxygen for hours in an artificially pressurized cabin while wearing a pressurized flying suit as an extra protection in case of cabin decompression.[41]

Air compression, however, is not practicable above 80,000 feet. Travel outside the breathable atmosphere, whether into space or to the bottom of the sea, necessitates living inside a hermetically sealed compartment, a completely airtight ecological system in which carbon dioxide exhaled by the traveler is constantly replaced by an onboard supply of pure oxygen or some combination approximating the nitrogen-oxygen composition at sea level. In this area of space flight research—space cabin environment—the Air Force achieved preeminence in the early fifties with the development of the first sealed space cabin.

The sealed space cabin had two essential precursors. One was the sealed gondola for stratospheric ballooning, used by the Swiss twins Auguste and Jean Piccard in several flights to altitudes of around 10 miles in the 1930s and in the *Explorer II* ascent of 1935, which carried Army experimenters Orvil A. Anderson and A. W. Stevens to 72,335 feet and set a record that stood for 20 years.[42] The other was the closed underwater environment of the bathysphere, used for many years in deep-sea exploration, and of the submarine. In the fifties, Air Force research on the sealed space cabin paralleled similar work by Navy scientists on an environmental control system for the new atomic-powered submarines, which were being designed to remain totally submerged for months.[43]

In 1952, Fritz Haber, of the Air Force School of Aviation Medicine, drew blueprints for a sealed chamber to be used for space medicine research; at the urging of Hubertus Strughold the Air Force let a contract for its construction. The Guardite Company of Chicago delivered a completed cabin in the summer of 1954.[44] "Nobody took notice of a 'sealed cabin,' " recalled Strughold. "We had to have a name that would attract attention to our work. So I named it the 'Space Cabin Simulator.' "[45]

The cabin provided about 100 cubic feet of living space, room enough for an ordinary aircraft seat and a panel of lights, switches, and displays to test the psychological reactions of the subject. It had systems for air conditioning, oxygen supply and carbon dioxide absorption, urine distillation, and the recycling of the distilled urine together with air moisture to provide water pure enough to drink. Cabin pressure was maintained constantly at a level equivalent to an altitude of 18,000 to 25,000 feet.[46]

The space cabin simulator received its first national publicity in March 1956, when Airman D. F. Smith spent 24 hours in the chamber at San Antonio, performing a number of tasks for psychological monitoring and wearing instrumentation to record his heart action, temperature, and respiration rate. During the next two years, Lieutenant Colonel George R. Steinkamp, Captain Julian Ward, and George T. Hauty, who had charge of the simulations, gradually increased the duration of the tests. On February 16, 1958, four and a half months after

*Sputnik I* and after seven days in the sealed chamber, Airman Donald F. Farrell stepped out to be greeted by a crowd of newsmen and by Senator Lyndon B. Johnson. In this, the most famous experiment ever run in the original space cabin simulator, Farrell had spent his week completely isolated in an environment that duplicated life inside a spacecraft in every respect except the weightless condition.[47]

The Farrell experiment provided no unexpected physiological data. But Hauty, chiefly interested in the psychological portion of the simulation, reported that the daily log kept by Farrell showed a deterioration from good spirits to "the seemingly abrupt onset of frank hostility." Farrell's mental condition "reached the point of becoming the single conceivable reason for a premature termination of the flight." Hauty noted that Farrell's proficiency at tasks assigned to him also deteriorated severely as the experiment progressed.[48]

The psychological data from the early space cabin simulator tests, as well as observation of subjects in the isolation chamber at Wright-Patterson Air Force Base, were not encouraging. Major Charles A. Berry, an Air Force physician who later would work closely with the astronauts in Project Mercury, perhaps expressed the consensus among space medicine investigators by 1958: "The psychological problems presented by the exposure of man to an isolated, uncomfortable void seem to be more formidable than the physiological problems." [49]

## Matter From Space

Even after enclosing himself in a sealed cabin and adjusting to prolonged isolation, the first man in space ran the danger of being killed by decompression if his cabin were punctured by one of the myriad meteoroids, ranging in size from less than a millimeter up to several meters, that constantly bombard Earth's atmosphere.[50] Impact with a meteoroid, even one the size of a BB shot, conceivably could put a hole in the structure of a spacecraft and cause death to its occupant through either gradual or explosive cabin decompression.

In the forties and early fifties scientists varied widely in their guesses as to the probability of meteoroid impact. Fletcher G. Watson, a Harvard University astronomer, predicted in 1946 that at least one of every 25 space ships going to the Moon would be destroyed by collision with a meteoroid. Two years later George Grimminger, a mathematician with the Rand Corporation, estimated that a spacecraft with an exposed area of 1000 square feet would be hit by a particle with a diameter of ½ millimeter only about once every 15 years. As late as 1951, however, Fred L. Whipple of Harvard, one of the principal American authorities on meteoroids, was rather pessimistic about the chances of avoiding meteoroid penetration and suggested thick shielding on the spacecraft to guard against structural damage.[51]

The early instrumented satellites sent up by the Soviet Union and the United States did much to dispel the fears of the space flight enthusiasts about meteoroids.

The American satellite *Explorer I*, launched in January 1958, recorded only seven hits by micrometeoroids—particles considerably less than a millimeter in diameter—during the first month of its orbital life. Apparently none of these pieces of matter penetrated the satellite's outer skin. Data from the much larger Russian *Sputnik III*, sent into orbit in May 1958, indicated that an orbiting spacecraft with a surface of 1000 square meters (10,760 square feet) would be hit by a meteoroid weighing at least one gram only once every 14,000 hours. And *Explorer VI*, orbited by the United States in the late summer of 1959, encountered meteoroid dust particles only 28 times during the first two days it was in orbit.[52] These data prompted a human-factors specialist for one of the major aerospace firms to conclude that for low orbital missions in a manned spacecraft "the danger from meteorite [sic] penetration is minor to negligible in comparison to the other hazards of such flights."[53] Nevertheless, Project Mercury astronauts would wear a full-pressure suit, a closed ecological system in itself, so that if cabin decompression occurred each astronaut could live until his space capsule could be brought back to Earth.

## Space Radiation

In addition to weightlessness, g loads, air, water, and food supply, isolation, and meteoroids, the problems of space flight included protecting the passenger from different kinds of electromagnetic radiation found above the atmosphere. Of the varieties of radiations in space the most mysterious is cosmic radiation, the source of which presents one of the grandest puzzles in nuclear astrophysics. Some of this radiation possibly comes from the Sun, but the preponderance of the cosmic rays bombarding Earth's atmosphere evidently originates outside the solar system—thus the term "cosmic" radiation. High-energy cosmic ray primaries—subatomic particles, of which about 90 percent are protons of hydrogen and helium—slam into the atmosphere at velocities approaching the speed of light. Fifteen to 25 miles above Earth, the cosmic ray primaries collide with atoms and molecules in the thickening atmosphere, are broken up, and are converted into lower-energy rays called secondaries. Above 25 miles the atmosphere becomes too thin to absorb the cosmic ray primaries; since they are capable of penetrating a thick lead wall, it was futile to try to shield a spacecraft pilot completely. So in the early 1950s medical researchers, assuming that a space pilot would be exposed to some cosmic radiation, approached the problem primarily from the angle of establishing how large a dose a human being could tolerate.[54]

As with weightlessness and g-load research, the best postwar device for studying cosmic radiation was the instrumented sounding rocket. But the last of the rocket experiments with primates occurred in May 1952. From that time until animal rocket shots resumed in 1958, the only upper-atmospheric research rockets fired in the country were occasional Aerobees, launched by the Air Force to altitudes of about 150 miles.[55] These shots, carrying only instruments, brought back a modicum of data on cosmic rays. The prime instrument for cosmic ray re-

search from 1952 to 1958 was the oldest vehicle for human flight, the balloon. The postwar development of sturdier, larger, polyethylene balloons to replace rubber aerostats made possible higher and higher ascents with increasingly heavier loads. At the same time the expansion of balloon technology, leading to an increasing number of giant, shiny spheres floating over the United States, multiplied reports of and popular interest in "Unidentified Flying Objects." [56]

In the balloon-borne space radiation experiments of the fifties, the Navy carried out some notable manned ascents into the stratosphere. On November 8, 1956, for example, Lieutenant Commanders Malcolm D. Ross and M. L. Lewis, as part of the Navy's Strato-Lab program of manned ascents from northern latitudes, reached 76,000 feet, then an altitude record. Less than a year later Ross and Lewis sat in their cramped sealed gondola as their huge polyethylene balloon ascended to nearly 86,000 feet. And in late June 1958 the same two Navy aerostation veterans remained in the 70,000-80,000-foot region for almost 35 hours.[57]

The Navy also pioneered in the use of balloon-launched rockets (rockoons). The first successful rockoon launch occurred in August 1952 when, from a ship off the coast of Greenland, a University of Iowa team headed by physicist James A. Van Allen sent up a balloon from which a rocket ignited at 70,000 feet and climbed to an altitude of nearly 40 miles. The Navy did most of its upper-atmospheric research, however, with instrumented balloon flights carrying small organisms and insects. In May 1954, for example, General Mills, Incorporated, under contract to the Office of Naval Research, launched a polyethylene balloon, with a capacity of 3 million cubic feet, that carried cosmic ray emulsions—plates designed for recording the tracks of ionizing particles—to an altitude of 115,000 feet. Five years later, from Sioux Falls, South Dakota, Raven Industries launched an Office of Naval Research balloon biological package to a record altitude of 148,000 feet.[58]

The center of Air Force balloon research in the early 1950s was the Aeromedical Field Laboratory in New Mexico. From July 21, 1950, when Air Force personnel launched the first polyethylene balloon at Holloman Air Force Base, to December 18, 1958, the scientists at the field laboratory sent up 1000 research balloons, although only a small number of these ascents were designed expressly for cosmic ray study. In 1953 the Holloman researchers moved most of their balloon experiments to the northern United States, in the higher geomagnetic latitudes, where they could obtain increased exposure to cosmic ray primaries. During the next year they sent aloft a collection of radish seeds on a series of flights, compiling some 251 hours of exposure of the seeds above 80,000 feet. Monkeys, mice, rats, hamsters, and rabbits also drifted upward in balloons launched by Winzen Research, Incorporated, as a Holloman contractor, from Sault Ste. Marie, Michigan. The most interesting effect observed among the various test subjects was a striking increase in the number of gray hairs on black mice exposed to the high altitudes.[59]

The first solo manned ascent into the stratosphere was also principally an under-

taking of the field laboratory at Holloman. In 1956 field laboratory experimenters inaugurated Project Manhigh, a series of flights from northern sites using Winzen balloons, to test man's ability to live for prolonged periods in a sealed-cabin environment like that inside a spacecraft and to gather new data on cosmic radiation. David Simons, head of the Space Biology Branch at Holloman, was project officer for the Manhigh ascents. The initial flight, from Fleming Field, Minnesota, took place on June 2, 1957. Captain Joseph W. Kittinger stayed aloft inside his sealed gondola for nearly seven hours, breathing pure oxygen, making visual observations, and talking frequently with John P. Stapp, the flight surgeon, and other physicians on the ground. Kittinger spent two hours above 92,000 feet; his maximum altitude during the flight was 96,000 feet.[60]

About nine weeks later Simons himself entered the space equivalent region, suspended in a sealed capsule below a 3-million-cubic-foot polyethylene balloon launched from an open-face mine near Crosby, Minnesota. Simons exceeded Kittinger's mark for both duration and altitude, staying aloft 32 hours and remaining at 101,000 feet for about 5 hours. Simons was the first man in history to see the Sun set and then rise again from the edge of space. In the *Manhigh II* gondola he spent more time than anyone before him looking upward at the blackness of space and outward at the white and blue layers of the atmosphere. "The capsule seemed like a welcome window permitting a fabulous view and precious opportunities, not a prison or an enclosure," he related after the flight.[61]

In October 1958 an excessive temperature rise in the capsule forced a premature termination of the third Manhigh flight, carrying Lieutenant Clifton M. McClure.[62] Yet McClure's ascent, together with those of Kittinger and Simons, proved the workability of the sealed cabin for sustaining human life where "the environment is as hostile and very nearly as different in appearance as one would expect to observe from a satellite."[63] The environmental control system of the Manhigh capsule and the instrumentation for physiological telemetering were strikingly similar to those later used in the Mercury spacecraft.

With regard to cosmic radiation, however, the Manhigh flights, like numerous rocket, balloon, and laboratory experiments of previous and succeeding years, returned data that were either negative or inconclusive. During the *Manhigh II* ascent two containers of bread mold were attached to the underside of the capsule, and Simons wore emulsion plates on his arms and chest to measure cosmic ray penetration. The plates did show indications of several hits by so-called "heavy" primaries—cosmic ray particles made up of nuclear particles heavier than are found in hydrogen or helium—but years later the skin in the area of the plates revealed no effects of radiation.[64]

All these experiments left most scientists as reluctant to speculate about the hazards from cosmic rays in flight as they had been in the early fifties. Simons felt that in manned orbital flights following roughly equatorial orbits, where the spacecraft remained within the protective shielding of Earth's magnetic fields, the spacecraft pilot would be in no danger from cosmic radiation. Yet he remained

troubled by the possibility that a solar flare, a sudden burst of energy from the Sun, might precipitate a great increase in cosmic ray intensity during a space mission. About a twentyfold multiplication of cosmic radiation accompanied a solar flare of February 1956. Simons' concern with solar flares led him to the conclusion that continuous voice contact between ground stations and the space pilot would be essential, as well as stepped-up efforts to predict the flares.[65]

All proponents of manned space flight were alarmed when information transmitted from the first three Explorer satellites, launched during the first half of 1958, disclosed the existence of a huge envelope of radiation beyond the ionosphere. Evidently consisting of protons and electrons trapped in Earth's magnetic field, the radiation layer begins about 400 miles out in space and doubles in intensity about every 60 miles before tapering away about 1200 miles from Earth. This discovery was the first "Van Allen belt," named after James A. Van Allen, United States director of the International Geophysical Year radiation experiments. The *Pioneer III* probe, launched in December 1958, failed to reach escape velocity, but it did reveal that the radiation zone consisted not of one belt but of two at least—an inner belt of high-energy particles and an outer belt of less energetic particles. Two earlier Pioneer shots, in October and November, had shown that while the radiation zone was several thousand miles deep, it did not extend into space indefinitely.[66] Quite obviously, the doughnut-shaped Van Allen belts would pose a serious threat for manned travel in high orbits or interplanetary voyages. In the early manned ventures into space, however, a spacecraft could be placed in an orbit 100 to 150 miles from Earth, high enough to be free of atmospheric frictional drag, yet low enough to stay under the Van Allen radiation.[67]

The radiation hazards of space flight also include solar radiation. Solar heat, ultraviolet rays, and x-rays all become much more intense beyond the diffusive atmosphere of Earth, but they can be adequately counteracted by space cabin insulation, shielding, refractive paint, and other techniques. Advanced space missions may subject astronauts to dangers from other kinds of radiation, such as the radiation belts surrounding other planets or the radioactivity produced by a spacecraft with a nuclear powerplant.[68]

## A Reason for Research

During 1958, scientists and engineers, both military and civilian, talked more openly than they had in previous years about radiation dosages, meteoroid penetration, weightlessness, and the other anomalies of space travel. They received a considerably more respectful hearing. What made members of the Congress and Americans in general responsive to such discussions and interested in past research and future plans for space exploration were the ever-larger scientific satellites launched by the Soviet Union, beginning October 4, 1957. In the midst of the nationalistic humiliation following the Sputniks, not only space

rocketry but also medical research with rockets received an invaluable boost. In May 1958, Air Force physicians sent mice along on three reentry tests of the Able ablation nose cone for the Thor. Then, the following December and in May 1959, the Navy School of Aviation Medicine dispatched monkeys, sea-urchin eggs and sperm, molds, tissues, and seeds on two test firings of the Jupiter intermediate-range missile, carried out by the Army Ballistic Missile Agency.[63]

The new focus on space, the new curiosity about what went on beyond the atmosphere, the determination to "catch up" in the space race—these sentiments redounded to the benefit of those Americans who had been trying to solve the biological and technological puzzles of manned space flight long before there was a space race. Their principal stimulus was not international prestige or the drive for technological supremacy; it was a desire to discover the undiscovered, to probe into the unknown. And they believed that wherever man's instruments went, man should follow. The proponents of manned space flight in the United States could be found in several locations—in the military, in some universities, in the aerospace industry, even in the Congress. But an especially zealous contingent worked for NACA. Ultimately its members would become the engineering and managerial nucleus of the American program to rocket a man into orbit around Earth and bring him back.

# IIII

# Aeronautics to Astronautics: NACA Research

(1952–1957)

LITTLE known outside the military services and the aircraft industry, the National Advisory Committee for Aeronautics by the early 1950s had far outgrown its name and could look back on nearly four decades filled with landmark contributions to military and civilian aeronautics. NACA had matured much beyond its original "advisory" capacity, had established three national laboratories, and had become perhaps the world's foremost aeronautical research organization. Drag-reducing engine cowlings, wing fillets, retractable landing gear, thin swept wings, and new fuselage shapes for supersonic aircraft—these were only a few of the numerous innovations leading to improved airplane performance that were wholly or partially attributable to the agency. NACA had pioneered in institutionalized team research—"big science," as opposed to the "little science" of individual researchers working alone or in small academic groups—and over the years such activity had paid off handsomely for the Nation.[1] NACA's relative importance in the totality of American aeronautics had declined after the Second World War with the enormous increase in military research and development programs, but NACA did not exaggerate when it asserted that practically every airplane aloft reflected some aspect of its research achievements.

The contributions of NACA in aeronautics were spectacular, but regarding the inchoate discipline of astronautics, especially rocket propulsion research, the agency, like the rest of the country, was skeptical, conservative, reticent. The prevailing prewar attitude within NACA toward rocket technology was expressed in 1940 by Jerome C. Hunsaker, then a member and later chairman of NACA's Main Committee. Discussing an Army Air Corps contract with the California Institute of Technology for rocket research in relation to current NACA work on the deicing of aircraft windshields, Hunsaker said to Theodore von Kármán of CalTech, "You can have the Buck Rogers job." [2]

In the early postwar years the leaders of NACA viewed rocket experimentation, such as the program beginning in 1945 at the Pilotless Aircraft Research Sta-

tion, on Wallops Island, Virginia, as essentially a tool for aerodynamics research furthering the progress of supersonic flight within the atmosphere. NACA's annual report for 1948, for example, mentioned the heating rates generated on the noses of the V–2s then being fired at White Sands, but discussed the problem of structural heating only in the context of aircraft.[3]

At the request of the military services, the Langley, Lewis, and Ames laboratories did study the theoretical performance of missiles, the operation of rocket engines, the composition of rocket fuels, and automatic control arrangements for supersonic guided missiles and aircraft. But such research accounted for only a small percentage of the total NACA workload and budgetary allotments. The annual budget cuts suffered by NACA, beginning in 1949 and reaching a high point in 1954 when the agency received only a little more than half its request, perhaps intensified the scientific conservatism of the NACA leaders, while the Korean War once again shifted most NACA laboratory work to the "cleaning up" of military aircraft.[4] It was in this climate of declining support for flight research in 1953 that NACA Director Hugh L. Dryden, who less than ten years later would be helping manage a manned lunar-landing program, wrote, "I am reasonably sure that travel to the moon will not occur in my lifetime . . . ." [5]

## NACA Moves Toward Space

In the early 1950s, however, as a full-fledged program to develop large ballistic missiles got underway and as the rocket research airplanes reached higher into the stratosphere, NACA began to consider the prospect of space flight and what contributions the organization could make in this new area of inquiry. On June 24, 1952, the Committee on Aerodynamics, the most influential of NACA's various technical committees, met at Wallops Island. Toward the end of the meeting, committee member Robert J. Woods, the highly respected designer of "X" aircraft for the Bell Aircraft Corporation, suggested that since various groups and agencies were considering proposals for sending manned and unmanned vehicles into the upper atmosphere, NACA should set up a study group on "space flight and associated problems." To Woods, NACA was the logical agency to conduct research in spacecraft stability and control; such work would be a proper extension of current NACA activity. After some discussion the other members of the committee approved Woods' suggestion. They formally resolved that NACA should intensify its research on flight at altitudes between 12 and 50 miles and at speeds of mach 4 through 10, and "devote a modest effort to problems associated with unmanned and manned flight at altitudes from 50 miles to infinity and at speeds from Mach number 10 to the velocity of escape from the earth's gravity." On July 14 the NACA Executive Committee, the governing body of NACA, composed of practically all the members of the Main Committee, approved a slightly revised version of this resolution.[6]

Less than a month after the action of the Executive Committee, Henry J. E.

Reid, Director of the Langley Aeronautical Laboratory, appointed Clinton E. Brown, Charles H. Zimmerman, and William J. O'Sullivan, aeronautical engineers at the Virginia center, to work up a thorough proposal for research in upper-atmospheric and space flight. Specifically the Langley engineers were to suggest a suitable manned vehicle on which construction could be initiated within two years. Their proposal was to be reviewed by a board composed of representatives from the three NACA laboratories and NACA's High Speed Flight Station at Edwards Air Force Base, California.[7]

Throughout the next year and a half, the Langley study group, engineers at Ames and the flight station, and the review board worked on a plan for the new research instrument. There was wide divergence of opinion as to what should be the nature and objectives of the vehicle; some parties were even skeptical about the wisdom of any space-directed research. Reid, John Stack, and others at Langley favored modifying the X–2 research airplane, then under development by Bell Aircraft, to make it a device for manned flight above 12 miles.[8] Smith J. DeFrance, one of the early Langley engineers who had become Director of the Ames Aeronautical Laboratory when it opened in 1941, originally opposed Woods' idea for a study group on space flight because "it appears to verge on the developmental, and there is a question as to its importance. There are many more pressing and more realistic problems to be met and solved in the next ten years." DeFrance had concluded in the spring of 1952 that "a study group of any size is not warranted." [9]

In July 1954, however, representatives of NACA disclosed to the Air Force and the Navy their conclusions regarding the feasibility of an entirely new rocket-powered research airplane and suggested a tripartite program for the manned exploration of the upper atmosphere. NACA's views were based mainly on the findings and proposals of the Langley study group, which had been working on the problem since 1952 and had made a more detailed presentation than research teams from Ames and the High Speed Flight Station. NACA envisioned an aircraft that would fly as high as 50 miles and whose speed would reach perhaps mach 7 (approximately 5000 miles per hour). Such a craft would be especially valuable for studying the critical problems of aerodynamic heating, stability, and control at high altitudes and speeds. Data gathered on its flights "would contribute both to air-breathing supersonic aircraft . . . and to long-range high-altitude rocket-propelled vehicles operating at higher Mach numbers." Realizing that the temperatures generated on its return into the heavier atmosphere would be greater than on any previous airplane, NACA suggested as a structural metal Inconel–X, a new nickel-chrome alloy "capable of rapid heating to high temperatures (1200°F) without the development of high thermal stresses, or thermal buckling, and without appreciable loss of strength or stiffness." [10]

This long-range plan was shortly accepted by the Air Force and the Navy Bureau of Aeronautics and put into motion as the "X–15 project." In December 1954, NACA, the Air Force, and the Navy agreed to proceed with the project

under operating arrangements roughly similar to the previous "X" aircraft ventures. The Air Force had responsibility for finding a contractor and supervising design and construction; both the Air Force and the Navy would provide financial support; and NACA would act as technical director.[11]

As prime contractor for the X–15, the Air Force picked North American Aviation of Los Angeles. The performance specifications of the X–15 called for a rocket engine consuming anhydrous ammonia and liquid oxygen and providing some 57,000 pounds of thrust for as long as six minutes. This powerplant would be four times as big as that of the X–2. A highly sensitive flight-data system, thick upper and lower vertical stabilizers for aerodynamic control, small reaction jets burning hydrogen peroxide for control in the near-vacuum of the upper atmosphere, and a new structural material—these were some of the novel characteristics of the stub-winged craft.[12]

The X–15 would not fulfill its original design objectives until 1962, long after NACA had become NASA and in the same year that Project Mercury achieved its basic goals. Even so, the X–15 was by far the most ambitious, expensive, and publicized research undertaking in which NACA ever participated. Its eventual success stemmed largely from the imagination and ingenuity of the NACA engineers who had started planning for an advanced aerodynamic vehicle in 1952.

In 1954, the year of Major Arthur Murray's climb to about 17 miles in the X–1A, the idea of manned rocket flight to an altitude of 50 miles seemed exceedingly visionary. Most people in NACA, the military, the aircraft industry, and elsewhere assumed that over the years vehicles with substantial lift/drag ratios would evolve to higher and higher speeds and altitudes until, by skipping in and out of the atmosphere like a flat rock across the surface of a pond, they could fly around the world. Even then, however, there were those within NACA who took the Executive Committee's mandate for "research in space flight and associated problems" literally and who felt that the X–15 concept did not go far enough. They looked to the second part of the resolution adopted by the Committee on Aerodynamics and approved by the Executive Committee, which sanctioned "a modest effort" on the "problems associated with flight at altitudes from 50 miles to infinity and at speeds from Mach number 10 to the velocity of escape from the earth's gravity."

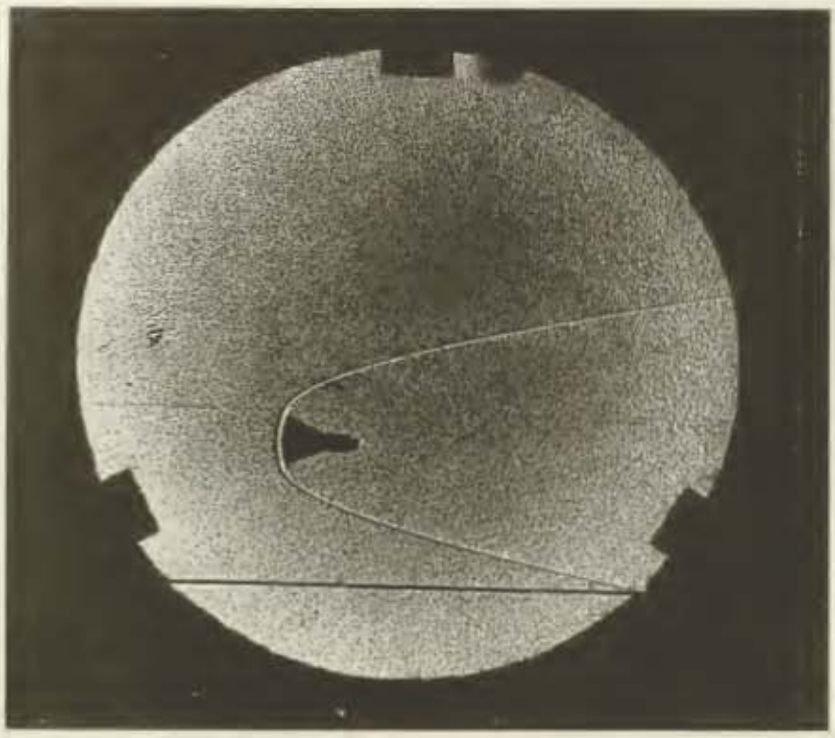
Some of the most "far out" aeronautical engineers working for NACA in the early fifties were employed at the Ames laboratory. As early as the summer of 1952, Ames engineers, experimenting at the supersonic free-flight, 10-inch-by-14-inch, and 6-inch-by-6-inch wind tunnels at the California site, had examined the aerodynamic problems of five kinds of space vehicles—glide, skip, ballistic, satellite, and interplanetary. They knew that the aerodynamic forces acting on a vehicle above 50 miles were relatively minor, as were problems of stability and control at such altitudes. They concluded, however, that a space vehicle should probably be controllable at lower altitudes, although it "may not be optimum from the point of view of simplicity, etc. . . ."[13]

## Reentry: Aerodynamics to Thermodynamics

The Ames study had been specifically requested by NACA Headquarters, which in its initial prospectus on the new research airplane project had identified stability and control in high-speed, high-altitude flight as one of two areas needing much additional research. The other and far more critical area was aerodynamic heating, which becomes acute as an object knifes into the atmosphere from the airless environment of space and collides with atmospheric molecules of ever-increasing density. For several years NACA researchers had been studying aerodynamic heating, which begins to be troublesome at about twice sonic speed. The X–15 program was established largely to return data on heating generated up to mach 7. But such investigations of thermal stress hardly approached the heating problem faced by the military services and the missile industry in their efforts to produce a durable warhead for an intercontinental missile. In a typical ICBM flight with a peak altitude of 900 miles and a range of 6500 miles, the stagnation temperature in the shock wave at the front of the nose cone could reach 12,000 degrees F. This is some 2000 degrees hotter than the surface of the Sun and 10 times the maximum surface temperature that was calculated for an X–15 trajectory.[14] Of the myriad puzzles involved in designing, building, and flying the Atlas, the first American ICBM, the most difficult and most expensive to solve was reentry heating. The popular term "thermal barrier" to describe the reentry problem was coined as an analogy to the "sonic barrier" of the mid-1940s, although research in the fifties would reveal that the problem could have been described more accurately as a "thermal thicket."

During June 1952, in the same summer that NACA had decided to move toward space flight research and had proposed an advanced research aircraft, one of the scientist-engineers at Ames had made the first real breakthrough in the search for a way to surmount the thermal barrier. He was Harry Julian Allen, a senior aeronautical engineer at Ames and chief of the High-Speed Research Division since 1945. The burly Allen, who signs his technical papers "H. Julian" but who is known familiarly as "Harvey," was 42 years old in 1952 and looked more like a football coach than a scientist. Holder of a bachelor of arts degree in engineering from Stanford University, Allen in 1935 had left the Stanford Guggenheim Aeronautical Laboratory, where he had received the degree of aeronautical engineer, to join the NACA staff at the Langley laboratory. When Ames was opened in 1941, he went west with Smith DeFrance and others from Langley.[15]

At Ames, Allen had invented a technique of firing a gun-launched model upstream through a supersonic wind tunnel to study aerodynamic behavior at high mach numbers. This notion led to the construction of the Ames supersonic free-flight wind tunnel, opened in 1949. The tunnel had a test section 18 feet long, one foot wide, and two feet high. By forcing a draft through the tunnel at a speed of about mach 3 and by firing a model projectile upstream at a velocity



*This shadowgraph of the Mercury reentry configuration was made in the Ames Supersonic Free-Flight Tunnel at a simulated speed of mach 10.*

of 8000 feet per second, the Ames researchers could simulate a mach number of about 15. Schlieren cameras set up at seven stations along the test section, three on the side and four on the top, made shadowgraphs to show airflow characteristics over the model and thus determine the aerodynamic forces experienced. During the 1950s the facility, constructed at an original cost of only about $20,000, was to prove one of NACA's most valuable tools for hypersonic investigation.[16]

As a member of one of the panels of the Department of Defense Research and Development Board, a group charged with supervising weapons research, Allen was intimately familiar with the payload protection dilemma confronting the Air Force and Convair, the prime contractor for the difficult Atlas project.[17] In their designs the Convair engineers had already provided that at the peak of the Atlas' trajectory, its nose, containing a nuclear warhead, would separate from the sustainer rocket and fall freely toward its target. These exponents of the ICBM knew that without adequate thermal protection the nuclear payload would burn up during its descent through the atmosphere.

Fifty years of progress in aeronautics had produced more and more slender and streamlined aircraft shapes, the objective being to reduce aerodynamic drag and increase speed. In approaching the Atlas reentry enigma, the Convair group drew from the huge reservoir of knowledge accumulated over the years by aerodynamicists and structures experts dealing with airplanes, rockets, and air-breathing missiles. The men at Convair fed their data into a digital computer, which was supposed to help them calculate the optimum design for structural strength, resistance to heat, and free-flight stability in the separable nose section of a long-range rocket. The computer indicated that a long, needle-nosed configuration for the reentry body, similar to that of the rocket research airplanes, would be best for the ICBM. But tests of this configuration, using metal models in the supersonic wind tunnel at Ames and in rocket launches at Wallops Island, showed that so much heat would be transferred to the vehicle that the warhead would

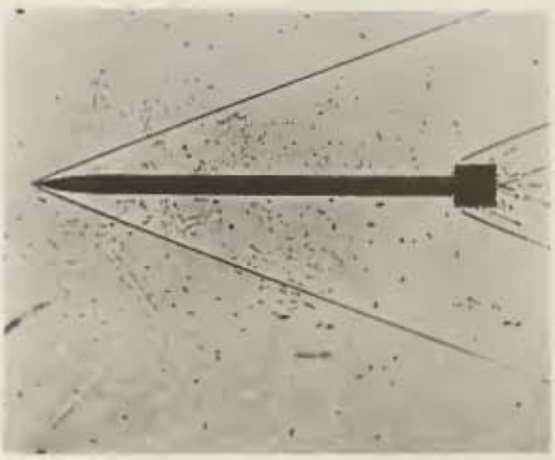
shortly vaporize as it plunged through the atmosphere. No protection system known at that time could prevent its destruction by aerodynamic heating.[18]

This disclosure evoked another spate of predictions that an intercontinental military rocket would not be feasible for many years. And while relatively few people were thinking seriously about manned space flight in the early fifties, those who were also understood that something radical would have to be done on the problem of reentry before it would be practicable to send a man into space and recover him.

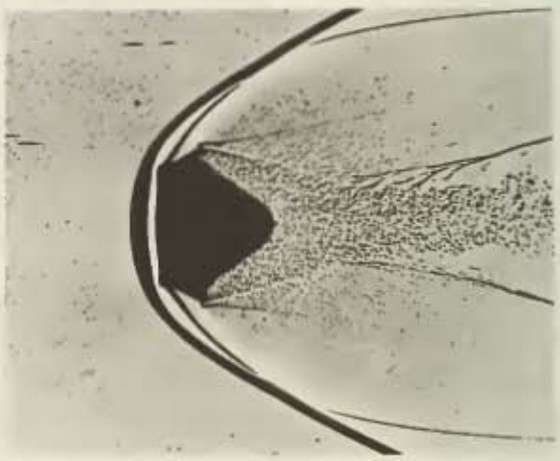
The man who did something radical was Allen. As Allen put it, the Convair engineers "cut off their computer too soon." He took the sharpnosed Atlas reentry shape and began making mathematical calculations, using only a pad and pencil. Eventually he reached a conclusion that seemingly contradicted all the years of aeronautical research and streamlined aircraft design. For Allen's analysis showed that the best way to cut down reentry heating was to discard a great deal of one's thinking about orthodox aerodynamics and deliberately design a vehicle that was the opposite of streamlined. "Half the heat generated by friction was going into the missiles," recalled Allen. "I reasoned we had to deflect the heat into the air and let it dissipate. Therefore streamlined shapes were the worst possible; they had to be blunt." The Ames researcher determined that the amount of heat absorbed by an object descending into the atmosphere depended on the ratio between pressure drag and viscous or frictional drag. The designer of a reentry body, by shaping the body bluntly, could alter pressure drag and thus throw off much of the heat into the surrounding air. When the bluff body collided with stratospheric pressures at reentry speeds, it would produce a "strong bow shock wave" in front of, and thus detached from, the nose. The shock wave, the air itself, would absorb much of the kinetic energy transformed into heat as the object entered the atmosphere.[19]

Allen personally submitted his findings to select persons in the missile industry in September 1952. A secret NACA report memorandum embodying his conclusions on the blunt-nose design, coauthored by Alfred J. Eggers of Ames, went out to industrial firms and the military the next spring. The report bore the date April 28, 1953, but six years passed before the paper was declassified and published in the annual report of NACA.[20]

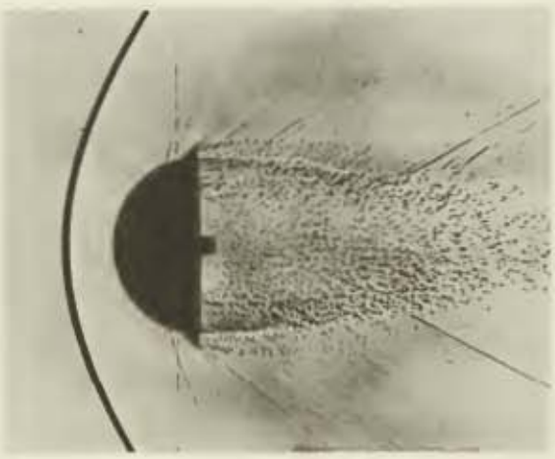
For his conception of the blunt-body configuration, Allen received the NACA Distinguished Service Medal in 1957. The award brought sharp criticism from H. H. Nininger, director of the American Meteorite Museum at Sedona, Arizona, who asserted that he had first proposed the blunt nose for reentry vehicles. In August 1952, Nininger, a recognized authority on meteorites, had suggested to the Ames laboratory that a blunt shape appeared promising for missile warheads. Nininger based his conclusion on his studies of tektites and meteorites, contending that the melting process experienced by a meteorite during its descent through the aerodynamic atmosphere furnished a lubricant enabling the object to overcome air resistance. Nininger's letter evidently came to Ames some weeks after Allen,



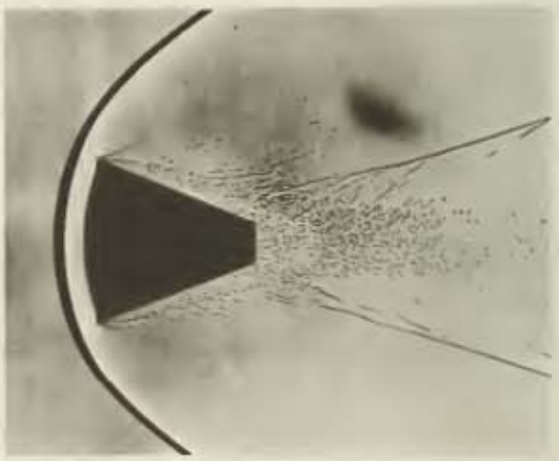
*Initial missile concept*



*Missile nose cones, 1953–57*



*Blunt body concept, 1957*



*Manned capsule concept, 1957*

*Ten years of intensive aerodynamic research preceded the final determination of the reentry configuration for Project Mercury. Most of this was generated by the military development of ballistic missiles. As these schlieren photographs of wind tunnel tests indicate, the departure point of atmospheric aerodynamic configuration was to change drastically under the new heat and stability conditions imposed by Mercury's demanding sequence of atmospheric flight-spaceflight-reentry-atmospheric flight-landing.*

assisted by Eggers, had completed his calculations on the relationship between warhead shape and heat convection. At any rate, what Allen wanted to do was exactly the reverse of Nininger's suggestion: deliberately to shape a reentry body bluntly in order to *increase* air resistance and dissipate a greater amount of the heat produced by the object into the atmosphere.[21]

Allen's high-drag, blunt-nose principle was of enormous interest and benefit to the missile designers. It led directly to the Mark I and Mark II nose cones developed by the General Electric Company for the Atlas and later for the Thor.

Years after the discovery, James H. Doolittle, chairman of NACA's Main Committee, pointed out that "every U.S. ballistic missile warhead is designed in accordance with his once radical precept." [22] In 1952 the problems of the missilemen were not of immediate concern to designers of manned flight systems, not even to those drawing up plans for the X–15, which would encounter a greater heating load than any previous airplane. Yet Allen's presentation of a new way to minimize the aerodynamic heating of reentry not only made possible an ICBM within a few years but "marked the potential beginning of manned space flight, with all of its attendant new structures and materials problems." [23]

The blunt-nose concept was just that—a concept. Succeeding years would see much experimentation with spheres, cylinders, blunted ogives, and even concave shapes at the supersonic free-flight tunnel, ballistic ranges, and various other facilities at Ames, at the 11-inch hypersonic tunnel at Langley, and at the Pilotless Aircraft Research Station on Wallops Island.[24] As aerodynamicists began thinking about space flight they would propose a variety of configurations for potential manned space vehicles, although all of the designs would feature some degree of bluntness. Finally, blunting a reentry body furnished only part of the solution to the heating problem. Allen's calculations presupposed that some kind of new thermal protection material would be used for the structure of a high-drag body. In 1952, aircraft designers and structures engineers were working mainly with aluminum, magnesium, and titanium, and were giving some attention to such heat-resistant alloys as Monel K, a nickel-and-steel metal used in the X–2, and Inconel-X, the basic alloy for the X–15.[25] But it would take much "hotter" materials to protect the payloads of the intercontinental and intermediate-range ballistic missiles—the Atlas, the Thor, the Jupiter, and later the Titan. Far more materials research was needed before the recovery of a manned spacecraft would be practicable.

Early in 1956, the Army Ballistic Missile Agency at Huntsville, Alabama, modified some of its medium-range Redstones in order to extend the studies of reentry thermodynamics that the Army had pursued at Redstone Arsenal since 1953. As modified, the Redstone became a multistage vehicle, which Wernher von Braun and his colleagues called the "Jupiter C" (for Composite Reentry Test Vehicle). Meanwhile the Air Force conducted its own investigations of reentry in conjunction with its nose-cone contractors, General Electric and the Avco Manufacturing Corporation, using a special multistage test rocket called the X–17, manufactured by the Lockheed Aircraft Corporation.[26]

Two principal techniques for protecting the interior of the nose cone offered themselves—"heat sink" and "ablation." The heat sink approach involved using a highly conductive metal such as copper or beryllium to absorb the reentry heat, thus storing it and providing a mass sufficient to keep the metal from melting. The major drawback of a heat sink was its heaviness, especially one made of copper. In the ablation method the nose cone was covered with some ceramic material, such as fiber glass, which vaporized or "ablated" during the period of reentry heat-

ing. The vaporizing of the material, the conversion of a solid into a gas, dissipated or carried away the heat. Thus the essence of the ablation technique was deliberately burning part of the exterior surface of the reentry body, but designing the body so that the surface would not burn through completely.[27]

Apparently no consensus existed among students of the reentry problem by late 1957. The "first generation" ICBM nose cones produced by General Electric, the Mark I and Mark II, were blunt, heavy copper heat sinks, and the Air Force had decided to use the Mark II on its Thor intermediate-range missile. But the Air Force's full-scale tests of the lighter, more sophisticated, but more difficult and less tidy ablation process had not begun yet. Meanwhile, the Army and the Vitro Corporation, using the exhaust of liquid rocket motors as a heat source and the hybrid Redstone in reentry simulations, demonstrated to their own satisfaction the practicability of consuming part of the structural material during its use, the principle of ablation. The Army's Jupiter-C shot of August 8, 1957, carrying a scale model Jupiter nose cone to an altitude of 600 miles and a range of 1200 miles, supposedly "proved the feasibility of the ablative-type nose cone" and "fulfilled the mission of the reentry test program." [28] Yet the Ballistic Missile Agency engineers at Redstone Arsenal were working only on the intermediate-range Jupiter, not on an ICBM. The question of whether an Atlas warhead or a manned reentry vehicle could best be protected by the heat-sink or ablation method, or by either, remained undetermined. Much time and effort would be expended before the Army's claims for ablation would be fully verified and accepted.

NACA's official role in this accelerated program of materials research was that of tester and verifier. Even so, the NACA experimenters greatly enlarged their knowledge of thermodynamics, became well grounded in the new technology of thermal protection, and prepared themselves to cope with the heating loads to be encountered in manned space flight.

At the request of the Air Force, the Army, and also the Navy (which was involved with the Polaris after 1956), NACA devoted an encreasing portion of its facilities and technical staff to tests of such metals as copper, tungsten, molybdenum, and later beryllium for heat sinks, and of ablating materials like teflon, nylon, and fiber glass. During 1955–1956 the installation of several kinds of high-temperature jets at the Langley and Lewis laboratories greatly aided NACA thermodynamics research. These included, at Langley, an acid-ammonia rocket jet providing a maximum temperature of 4100 degrees F and a gas stream velocity of 7000 feet per second, an ethylene-air jet yielding temperatures up to 3500 degrees F, and a pebble-bed heater, wherein a stream of hot air was passed through a bed of incandescent ceramic spheres. Both Langley and Lewis had electric arc jet facilities, in which a high-intensity arc was used to give energy to compressed air and raise air pressure and temperatures. The hot, high-pressure air then shot through a nozzle to produce a stream temperature of about 12,000 degrees F. NACA investigators used these high-temperature jets and other research tools, including the 11-inch hypersonic tunnel at Langley, to gather data eventually rein-

forcing the Army's contention that ablation was the most effective thermal protection method.[29]

Meanwhile Maxime A. Faget, Paul E. Purser, and other members of the Langley Pilotless Aircraft Research Division, working under the supervision of Robert R. Gilruth, used multistage, solid-propellant rockets for studying heat transfer on variations of Allen's basic blunt heatshield configuration. Robert O. Piland, for example, put together the first multistage vehicle to attain mach 10. Faget served as a regular NACA member and Purser was an alternate member of a Department of Defense panel called the Polaris Task Group, set up to give advice on the development of the Navy's intermediate-range, solid-fueled Polaris, which was to be launched from submerged submarines. NACA worked with the Atomic Energy Commission and the Lockheed Aircraft Corporation, prime contractor for the Polaris, in developing the heat-sink nose cone used on the early versions of the sea-based missile.[30]

Although there were some 30 different wind tunnels at Langley, the members of the Pilotless Aircraft Research Division (PARD) firmly believed in the superiority of their rocket-launch methods for acquiring information on heating loads and heat transfer, heat-resistant materials, and the aerodynamic behavior of bodies entering the atmosphere. As Faget said, "The PARD story shows how engineering experimentalists may triumph over theoreticians with preconceptions. Our rockets measured heat transfer that the tunnels couldn't touch at that time." Joseph A. Shortal, chief of PARD since 1951, recalled, "PARD made us more than aeronautical engineers and aerodynamicists. We became truly an astronautically oriented research and development team out at Wallops."[31]

The Ames experimenters, on the other hand, were just as firmly convinced that their wind tunnels and ballistic ranges represented the simplest, most economical, and most reliable tools for hypersonic research. To the Ames group, rocket shots were troublesome and expensive, and rocket telemetry was unreliable. As one Ames engineer put it, "You might get a lot of data but since you didn't control the experiment you didn't know exactly what it meant."[32]

The Ames devotion to laboratory techniques, the determination to do more and more in heating and materials research without resorting to rockets, furnished the impetus for a new test instrument devised by Alfred J. Eggers, Jr., in the mid-fifties. Eggers, born in 1922 in Omaha, had joined the research staff at Ames in the fall of 1944, after completing his bachelor of arts degree at the University of Omaha. He pursued graduate studies at Stanford University in nearby Palo Alto, where he received a Master of Science degree in aeronautical engineering in 1949 and a Ph.D. in 1956.[33] For years Eggers had worked with Allen and others at Ames on the aerodynamic and thermodynamic problems of hypervelocity flight, and as a conceptualizer at the California center he came to be regarded as second only to the originator of the blunt-nose reentry principle.

Eggers assumed that the major heating loads of reentry would be encountered within an altitude interval of 100,000 feet. So he designed a straight, trumpet-

shaped supersonic nozzle with a maximum diameter of 20 inches and a length of 20 feet, which in terms of the model scale used was equivalent to 100,000 feet of thickening atmosphere. A hypervelocity gas gun launched a scale model upstream through the nozzle to a settling chamber. While in free flight through the nozzle to the chamber, the model passed through ever-denser air, thus closely approximating the flight history of a long-range ballistic missile. Since the apparatus simulated both motion and heating experiences, Eggers called the combination of hypervelocity gun and supersonic nozzle "an atmosphere entry simulator." [34]

Eggers calculated that using a model only .36 inch in diameter and weighing .005 pound, he could simulate the acrodynamic heating generated by an object three feet in diameter, weighing 5000 pounds, and having a range of 4000 miles. "In the simplest test," he said, "the simulator could provide with one photograph of a model rather substantial evidence as to whether or not the corresponding missile would remain essentially intact while traversing the atmosphere." The reentry research technique, proposed in 1955, went into operation during the next year. Construction of a larger version began in 1958. Eggers' atmosphere entry simulator proved especially useful in materials research at Ames. Like the high-temperature jets at Langley and Lewis, the rocket tests at Wallops Island, the Army's Jupiter-C shots from Cape Canaveral, and other experimental methods, it yielded data that later pointed toward ablation as the best method for protecting the interior of reentry bodies.[35]

Although the official focus of the NACA materials test program remained on missile warhead development, such activity was an obvious prerequisite to manned space flight. And the experience of men like Gilruth, Faget, Purser, and Shortal in the years before the Sputniks had a direct influence on their plans for shielding a human rider from the heat of atmospheric friction. Meanwhile other NACA engineers, especially at Langley and at the High Speed Flight Station, were working closely with the Navy, the Air Force, and North American Aviation on the X–15 project. At Cleveland, Lewis propulsion specialists were studying rocket powerplants and fuels as well as cooperating with Langley and Flight Station representatives in designing, operating, and studying reaction control systems for hypersonic aircraft and reentry vehicles.

## A Moon for a Man

Others in NACA, sensing the potential for manned space exploration that accompanied propulsion advances in military rocketry, began considering designs for a vehicle with which man could take his first step above the atmosphere. Early in 1954, Eggers, Julian Allen, and Stanford E. Neice of Ames put together a classic theoretical discussion of different space flight configurations in a paper entitled "A Comparative Analysis of the Performance of Long-Range Hypervelocity Vehicles." The research engineers examined the relative advantages, in terms of range and the ratio between payload and total weight, of three kinds




*Alfred J. Eggers, Jr., stands beside the Atmospheric Entry Simulator he invented in 1958 as a laboratory means of studying the problems of aerodynamic heating and thermal stresses during reentry. The tubular tank in the foreground held air under high pressure. When a valve was opened, the air flowed through the test section (the dark area under the high-voltage signs) into the chimneylike vacuum tank. As the airstream moved, a high-velocity gun fired a test model through the chamber in a right-to-left direction. Instruments photographed the model in flight, timed the flight, and studied the nature of the incandescence generated by the aerodynamic heating.*

of manned hypersonic vehicles: ballistic, a blunt non-lifting, high-drag projectile; skip; and glide, the last two designs also having fairly blunt noses but possessing some lifting ability. For satellite missions all three vehicles might be boosted to orbital velocity by a rocket and could then separate from the rocket and go into free flight, or orbit.

Eggers, Allen, and Neice found that the skip vehicle, which would return to Earth by performing an intricate series of progressively steeper dips into the atmosphere, would need an extremely powerful boost to circumnavigate the globe, and also would encounter a prohibitively large amount of aerodynamic heating.[36] By contrast, the glider, although heavy, would require less boost and would keep the g forces imposed on the pilot during reentry at a quite acceptable level. Like the skip craft, the glider would provide the advantage of pilot control during the landing phase. It would radiate heat well, but since its thermodynamic loads still would be high, the glider might experience dangerous interior heating during a "global" (satellite) mission. So the authors suggested a high-lift glider; like the high-lift-over-drag glider, it would have a delta-wing configuration but also would feature thick, rounded sides and bottom to minimize interior heating. It would enter the atmosphere at a high angle of attack, then level off at lower altitudes to increase the lift/drag ratio.

The ballistic vehicle, the simplest approach of the three, could not be controlled aerodynamically, but its blunt shape provided superior thermal protection, and its relatively light weight gave it a longer range. If it entered the atmosphere at a low angle, deceleration forces could be kept at or below 10 g, with 5 g lasting for 1 minute and 2 g for not over 3 minutes. Therefore the three NACA researchers concluded that "the ballistic vehicle appears to be a practical man-carrying machine, provided extreme care is exercised in supporting the man during atmospheric entry." [37]

As time passed, Eggers personally became convinced of the overall desirability of the manned satellite glider as opposed to the ballistic satellite. He revealed his preference in a modified version of the earlier paper done with Allen and Neice, which he read before the annual meeting of the American Rocket Society in San Francisco, in June 1957. Eggers was skeptical about the relatively high heating loads and the deceleration forces characteristic of ballistic reentry, even at a small entry angle. He warned that "the g's are sufficiently high to require that extreme care be given to the support of an occupant of a ballistic vehicle during atmospheric reentry," and pointed out that such an object, entering the atmosphere along a shallow trajectory so as to hold deceleration down to 7.5 g, would generate a surface temperature of at least 2500 degrees F. Thus, in Eggers' judgment, "the glide vehicle is generally better suited than the ballistic vehicle for manned flight at hypersonic velocities." [38]

Eggers realized that his glider design, if actually built, would be too heavy for the military rockets then under development. At the same time he remained concerned about the deceleration loads imposed on the space pilot and the heating

loads on the spacecraft structure. He also saw the difficulty of recovering a ballistic satellite, which since it was noncontrollable in the atmosphere, would have to land somewhere in a target area of several thousand square miles. As a consequence of these apprehensions, during the last half of 1957 he sketched a semiballistic device for manned orbital flight, blunt but having a certain amount of aerodynamic lift, with a nearly flat top and a round, deep bottom for heat protection. This design, which Eggers called the "M–1," fell about halfway between the high-lift glider and the ballistic vehicle discussed in his 1954 NACA study with Allen and Neice. About 10 feet wide and nearly seven feet long, the M–1 from above looked like an isosceles triangle rounded at its apex.[39] A more graphic description was offered by Paul Purser, who called it a "¼ egg lifting shape." [40] The M–1's limited amount of lift would give it about 200 miles of lateral maneuverability during its descent through the atmosphere and about 800 miles of longitudinal discretion over its landing point. Eggers' calculations indicated that skillful piloting could keep reentry deceleration at about 2 g.[41]

## Air Force Provides a Need

The work of Eggers and others on designs for man-carrying space vehicles had been stimulated not only by general progress in long-range rocketry but also by the growing interest of the Air Force in manned space flight. Eggers knew that ever since the war the Air Force, through the Rand Corporation, had been considering the military potential of space technology, and that since early 1956 the service had been proceeding cautiously with contract feasibility studies of manned satellites.

The impetus for these feasibility studies came from a staff meeting at the headquarters of the Air Research and Development Command (ARDC) at Baltimore, on February 15, 1956. During the course of the meeting, General Thomas S. Power, Commander of ARDC, expressed impatience with the failure of his "idea men" to propose any advanced flight systems that could be undertaken after the X–15. Work should begin now, he declared, on two or three separate approaches beyond the X–15, including a vehicle that would operate outside the atmosphere without wings. He suggested that a manned ballistic rocket might be "eventually capable of useful intercontinental military and commercial transport and cargo operation." But the main benefit of having an advanced research project underway, Power pointed out, was that the Air Force could more easily acquire funds for the "general technical work needed." [42]

Thus prodded into action, Power's staff quickly proposed two separate research projects. The first called for a "Manned Glide Rocket Research System"—a rocket-launched glider that would operate initially at an altitude of about 400,000 feet and a speed of mach 21. The other, termed "Manned Ballistic Rocket Research System," would be a separable manned nose cone, or capsule, the final stage of an ICBM. Such a vehicle could lead to the "quick reaction delivery of

high priority logistics to any place on Earth," as suggested by Power, or to a manned satellite. Power's staff argued that the manned ballistic concept offered the greater promise, because the solution to the outstanding technical problems, the most critical of which was aerodynamic heating, would result from current ICBM research and development; because existing ICBMs would furnish the booster system, so that efforts could be concentrated on the capsule; and because the ballistic vehicle possibly could be developed by 1960. Either program, however, should be pushed rapidly so that the Air Force could protect its own interests in the field of space flight.[43]

In March 1956, ARDC established two research projects, one for the glide rocket system, the other, known as Task 27544, for the manned ballistic capsule. ARDC planners shortly held briefings on the two proposed systems for its missile-oriented Western Development Division, in California, and for its pilot-oriented Wright Air Development Center, in Ohio. Other briefings were held for NACA representatives and for aircraft and missile contractors. Then, in October, Major George D. Colchagoff of Power's staff described the basic aspects of the two advanced systems to a classified session of the American Rocket Society's annual meeting in Los Angeles.[44]

Since the Weapons Systems Plans Office of ARDC Headquarters never received the $200,000 it had requested for its own feasibility studies, the command had to content itself with encouraging privately financed contractor research.[45] In particular Avco, then trying to develop serviceable nose cones for the Thor and Atlas missiles, was urged to study the manned ballistic capsule. In November 1956, Avco submitted to the Research and Development Command a preliminary study embodying its conclusions on the ballistic approach to manned space flight. ARDC still was short of funds, so Avco and other corporations continued to use their own money for further investigations.[46]

While ARDC promoted these systems studies and sponsored extensive research in human factors at the School of Aviation Medicine in Texas, at the Aeromedical Field Laboratory in New Mexico, and at the Aeromedical Laboratory in Ohio, it also sought to gain acceptance for its ideas within the Air Force organizational structure. On July 29, 1957, the Ad Hoc Committee of the Air Force Scientific Advisory Board, meeting at the Rand Corporation's offices in Santa Monica, California, heard presentations from the Ballistic Missile Division on ballistic missiles for Earth-orbital and lunar flights, and from ARDC Headquarters on the two advanced flight systems then under study. Brigadier General Don D. Flickinger, ARDC's Director of Human Factors, stated that from a medical standpoint sufficient knowledge and expertise already existed to support a manned space venture.[47]

Although the industrial firms investigated mainly the manned ballistic capsule, NACA, following the traditional approach of building up to higher and higher flight regimes, centered its efforts on the glide-rocket concept for most of 1957. Since late the previous year, when NACA had agreed in principle to an ARDC

invitation to cooperate on the Manned Glide Rocket Research System, as they were doing for the X–15, small teams of engineers at the Langley, Lewis, and Ames laboratories had carried on feasibility and design studies.[48] In January 1957 the Ames group reported its conclusions on a new rocket-powered vehicle for "efficient hypersonic flight," featuring a flat-top, round-bottom configuration. Interestingly enough, the Ames document contained as an appendix a minority report written by Langley aerodynamicists—mostly from the Flight Research, Instrument Research, and Pilotless Aircraft Research Divisions—recommending that a nonlifting spherical capsule be considered for global flight before a glide rocket.[49] "The appendix was widely read and discussed at Langley at the time," recalled Hartley A. Soulé, a Langley senior engineer, "but there was little interest expressed in work on the proposal." He continued:

> . . . aside from the environment that limited the NACA mission to terrestrial transportation, the proposal was criticized on technical grounds. The report suggested that landings be made in the western half of the United States, not a very small area. The spherical shape was suggested so that the attitude would not be important during reentry. The shape was specifically criticized because the weight of material to completely shield the surface from the reentry heat would probably preclude the launching with programmed ICBM boosters. Further, the lack of [body] orientation might result in harm to the occupant during the deceleration period.[50]

NACA study groups continued their investigations of manned glide rocket concepts through the spring and summer. In September 1957 a formal "Study of the Feasibility of a Hypersonic Research Airplane" appeared, bearing the imprimatur of the whole NACA but influenced primarily by Langley proponents of a raised-top, flat-bottom glider configuration.[51]

A few days later, on October 4, *Sputnik I* shot into orbit and forcibly opened the Space Age. The spectacular Russian achievement wrought a remarkable alteration in practically everyone's thinking about space exploration, especially about the need for a serious, concerted effort to achieve manned space flight. New urgency attended the opening of a long-planned NACA conference beginning October 15 at Ames, which was to bring together representatives from the various NACA laboratories in an effort to resolve the conflict in aerodynamic thinking between advocates of round and flat bottoms for the proposed hypervelocity glider. Termed the "Round Three Conference," the Ames meeting produced the fundamental concept for what would become the X–20 or Dyna-Soar (for dynamic soaring) project—a delta-wing, flat-bottom, rocket-propelled glider capable of reaching a velocity of mach 17.5, almost 13,000 miles per hour, and a peak altitude of perhaps 75 miles.[52]

Although they had been working mainly on the hypersonic glider, as requested by the Air Force, the research engineers of PARD, in tidewater Virginia, also had been spending more and more time thinking about how to transmute missile reentry bodies into machines for carrying man in low Earth orbit. Their advocacy, along with that of other Langley workers, of a spherical capsule early

that year had indicated their growing interest in making the quantum jump from hypersonic, upper-atmospheric, lift/drag flight to orbital space flight in a nonlifting vehicle. At the Round Three Conference, Faget and Purser compared notes with Eggers, perhaps the leading hypervelocity theoretician in NACA. Eggers related his own conclusions: for orbital flight the design giving the highest proportion of payload to total weight was the compact, low lift/drag vehicle, having little or no wings, and embodying Allen's blunt-nose principle. He discussed the analytical studies of his semiballistic M–1, which had some lift but would, he estimated, weigh from 4000 to 7500 pounds. Eggers cautioned his NACA colleagues that a nonlifting, or pure ballistic, vehicle might subject the passenger to excessive deceleration forces.[53]

Faget and Purser returned to Langley convinced that a maximum concentration of effort to achieve manned orbital flight as quickly as possible was imperative.[54] Obviously this meant that in the months ahead their research should focus on the ballistic-capsule approach to orbiting a man. Both the hypersonic glider, which called for progressing to ever higher speeds and altitudes, and Eggers' M–1, also too heavy for any existing booster system, would take too long to develop. The manned ballistic vehicle combined a maximum of simplicity and heat protection with a minimum weight and offered the best chance of getting a man into space in a hurry. Henceforth the aerodynamicists in PARD, and space enthusiasts in other units of the Langley laboratory, turned from NACA's historic preoccupation with winged, aerodynamically controllable vehicles and devoted themselves to the study of "a man in a can on an ICBM," as some in the Air Force called it.[55]

After *Sputnik I*, the aircraft and missile corporations also stepped up their research on the ballistic capsule; throughout November and December their design studies and proposals flowed into ARDC Headquarters. The most active of the firms considering how to put a man on a missile still was Avco. On November 20, 1957, it submitted to ARDC its second and more detailed study of systems for manned space flight, entitled "Minimum Manned Satellite." The Avco document concluded that "a pure drag reentry vehicle is greatly superior in satisfying the overall system requirements," and that the best available rocket for boosting a manned satellite into an orbit about 127 miles from Earth was the Atlas. Still unproven, the Atlas was to make its first successful short-range flight (500 miles) on December 17, 1957. An Atlas-launched satellite, according to the Avco idea, would be a manned spherical capsule that would reenter the atmosphere on a stainless-steel-cloth parachute. Shaped like a shuttlecock, the parachute was supposed to brake the capsule through reentry. Then air pressure would expand the parachute to a diameter of 36 feet, and the capsule would land at a rate of 35 feet per second.

Avco requested $500,000 to cover the expense of a three-month study and the construction of a "mockup," or full-scale model, of the capsule containing some of its internal systems. But because the Ballistic Missile Division was skeptical

about the drag-brake apparatus, and because ARDC was uncertain about Air Force plans in general, a contract was not awarded. Avco engineers, believing that the limiting factor in putting a man in orbit was not the capsule but the development of a reliable booster, focused on the Atlas and began holding discussions with representatives of Convair, builder of the Atlas.[56]

## Jockeying for Position

On October 9, only five days after *Sputnik I*, the Ad Hoc Committee of the Air Force Scientific Advisory Board urged the development of "second generation" ICBMs that could be used as space boosters, proposed the eventual accomplishment of manned lunar missions by the Air Force, and recommended the launching of Air Force satellites for reconnaissance, communications, and weather prediction purposes as soon as possible. A few days later, Secretary of the Air Force James H. Douglas appointed a committee of 56 academic and corporate scientists and Air Force officers, headed by the eminent but controversial nuclear physicist Edward N. Teller, to "propose a line of positive action" for the Air Force in space exploration. Not surprisingly, the Teller Committee in its report of October 28 recommended a unified space program under Air Force leadership.[57]

Then, on December 10, 1957, Lieutenant General Donald L. Putt, Air Force Deputy Chief of Staff, Development, set up a "Directorate of Astronautics" for the Air Force. Brigadier General Homer A. Boushey, who sixteen years earlier had piloted the first rocket-assisted aircraft takeoff in this country, became head of the new office. The move quickly met opposition from Secretary of Defense Neil H. McElroy, who was chary about any of the services using the term "astronautics," and from William M. Holaday, newly appointed Defense Department Director of Guided Missiles, whom the *New York Times* quoted as charging that the Air Force wanted to "see if it can grab the limelight and establish a position." The furor within the Defense Department caused Putt to cancel the astronautics directorate on December 13, only three days after its establishment.[58]

*Sputnik II*, the dismayingly large, dog-carrying Soviet satellite, had gone into orbit on November 3. As the mood of national confusion intensified in the last weeks of 1957, Headquarters USAF ordered the Air Research and Development Command to prepare a comprehensive "astronautics program," including estimates of funding and projected advances in space technology over the next five years. ARDC, which had been working on its own 15-year plan for Air Force research and development in astronautics, now boiled its findings down to a five-year prospectus. ARDC's report went to Headquarters USAF on December 30, and at the end of the year of the Sputniks the five-year plan was under consideration in the Pentagon.[59]

In any Air Force push into astronautics, NACA presumably would play a key role as supplier of needed research data. The agency had done this for nearly four decades in aeronautics. Proceeding on this premise, Putt wrote NACA

Director Dryden on January 31, 1958, formally inviting NACA's participation in a man-in-space program with the Air Force, including both the boost-glide research airplane, soon to be dubbed Dyna-Soar, and "a manned one-orbit flight in a vehicle capable only of a satellite orbit. . . ." [60] Dryden promptly approved NACA cooperation on the first approach, although the research agency and the Air Force would not sign their formal agreement on the subject until the following May.[61] Regarding the satellite project offer, however, Dryden informed Putt that NACA was working on its own designs for a manned space capsule and would "coordinate" with the Air Force late in March, when NACA completed its studies.[62]

Behind NACA's apparent reluctance to follow the Air Force lead into manned satellite development was a conviction, held by some people at NACA Headquarters, but mainly by administrators and engineers of the Langley and Lewis laboratories, that the agency should broaden its activities as well as its outlook Moving into astronautics, NACA should leave behind its historic preoccupation with research and expand into systems development and flight operations—into the uncertain world of large contracts, full-scale flight operations, and public relations. NACA should, in short, assume the leadership of a new, broad-based national space program, having as one of its principal objectives to demonstrate the practicability of manned space flight.

So in the 10 months between the first Sputnik and the establishment of a manned space program under a new agency, NACA would follow a rather ambivalent course. On one hand it would continue its traditional research and consultative capacity, counseling the Air Force on space flight proposals and imparting its findings to industrial firms. But at the same time ambitious teams of engineers here and there in the NACA establishment would be preparing their organization and themselves to take a dominant role in the Nation's efforts in space.

# IV

## From NACA to NASA

(NOVEMBER 1957–SEPTEMBER 1958)

SPUTNIK II, carrying its canine passenger into orbit on November 3, 1957, made clear what the first Sputnik had only implied: the U.S.S.R. would eventually try to put a man in orbit. Americans read of this latest Soviet achievement and wondered how soon the West might be able to restore the technological and ideological balance. Throughout the United States, individuals and organizations were doing an uncommon amount of introspection. It was time for some rethinking and reexamination, for an inquiry into the nature, meaning, and direction of American government and society in the Space Age.

One of the most introspective Government agencies in the post-Sputnik period was the National Advisory Committee for Aeronautics. To most people in NACA it was obvious that the organization had reached a crisis in its proud but rather obscure history; unless NACA moved rapidly and adroitly it might very well be overwhelmed in the national clamor for radical departures. New guidelines for its future clearly were in order. On November 18, 19, and 20, 1957, aboard the carrier *Forrestal* off the eastern coast of Florida, NACA's key Committee on Aerodynamics held another of its periodic meetings. Carried on in a mood of patriotic concern and challenge created by the Sputniks, these discussions reinforced the growing conviction that NACA should do more in astronautics. Among the 22 representatives of industry, the military, and academic aeronautics making up the committee, a consensus emerged that "NACA should act now to avoid being ruled out of the field of space flight research," and that "increased emphasis should be placed on research on the problems of true space flight over extended periods of time." The committee then adopted a resolution calling for "an aggressive program . . . for increased NACA participation in upper atmosphere and space flight research." [1]

Two days after the Committee on Aerodynamics adjourned, the Main Committee of NACA met and voted to establish a Special Committee on Space Technology. H. Guyford Stever, a physicist and dean of the Massachusetts Institute of Technology, took charge of the heterogeneous group. The special committee was the first established by NACA to concern itself expressly and exclusively with space matters. It was "to survey the whole problem of space technology from the point of view of needed research and development and advise

the National Advisory Committee for Aeronautics with respect to actions which the NACA should take." [2] Appointed to the new committee were such diverse leaders in space science and technology as James A. Van Allen, Wernher von Braun, William H. Pickering, and W. Randolph Lovelace II.[3]

As apprehensive Americans watched the failure of the Vanguard test vehicle in December and the successful Jupiter-C launch of *Explorer I* in January, NACA continued to assess its potential role in the Space Age. Shortly after the Sputniks, NACA Director Hugh L. Dryden; Chairman James H. Doolittle; John F. Victory, the venerable executive secretary of NACA; and others at Headquarters in Washington had decided on the course NACA should follow in succeeding months. Assuming that now a unified space program would come into being, the NACA leaders wanted to ensure their organization a place in such a national enterprise. To Dryden, who largely guided the formulation of its strategy, NACA should proceed cautiously toward its minimum and yet most important objective—extension of its traditional preeminence as an aeronautical research organization into the higher realm of astronautics. This would involve a continuation of NACA's traditional function as planner, innovator, tester, and data-gatherer for the Defense Department and the missile and aircraft industry. While a larger role, entailing responsibilities for development, management, and flight operations in addition to research, very possibly could come to NACA in a national astronautics effort, publicly NACA should play down whatever ambitions for such a role individuals and groups within the agency might have.[4]

In keeping with this "soft-sell" philosophy and plan of attack, the Main Committee, at its regular meeting of January 16, 1958, resolved that any national undertaking in astronautics should combine the talents and facilities of the Defense Department, NACA, the National Academy of Sciences, and the National Science Foundation. In other words, national space activities should follow roughly the pattern of Project Vanguard. NACA, while taking part in the launching of space vehicles and acquiring more authority to let research contracts, should continue to function primarily as a research institution.[5] Dryden essentially reiterated this viewpoint in a speech which Victory read for him nine days later before the Institute of the Aeronautical Sciences in New York. The NACA Director proposed that the current division of labor among the military, industry, and NACA be perpetuated in a national space program, with NACA doing research and providing technical assistance and the military contracting with industry for hardware development.[6]

Then, the next month, the Main Committee considered and circulated a prospectus inspired by Abe Silverstein, Associate Director of the Lewis Aeronautical Laboratory, and written mainly by his senior engineers. Entitled "A Program for Expansion of NACA Research in Space Flight Technology," it called for a "major expansion" of NACA activity to "provide basic research in support of the development of manned satellites and the travel of man to the moon and nearby planets." The Lewis group proposed an enlargement of NACA's existing laboratories and

a new, separate installation for nuclear powerplant research. The cost of the expansion of the program, including the expense of contracted research, was estimated at $200 million. Nothing was said about giving NACA added development, management, and operational tasks in manned space flight programs.[7]

So by early February 1958, as the Eisenhower administration began wrestling with the complexities of formulating a national program for space exploration, NACA had taken the official position that with regard to space it neither wanted nor expected more than its historic niche in Government-financed science and engineering. While NACA should become a substantially bigger instrument for research, it should remain essentially a producer of data for use by others.

## Missiles to Manned Ballistic Satellites

The circumspect approach of NACA Headquarters to a national space program was only one of several being suggested formally in the winter of 1957–1958. Various other proposals came from the scientific community. In mid-October the American Rocket Society had called for a civilian space research and development agency. In November the National Academy of Sciences endorsed an idea for a National Space Establishment under civilian leadership. By April 1958 a total of 29 bills and resolutions relating to the organization of the Nation's space efforts would be introduced by members of the Congress. Almost everyone assumed that some sort of thorough-going reform legislation, probably creating an entirely new agency, was needed if the United States was to overcome the Soviet lead in space technology. On January 23, 1958, the Senate Preparedness Investigating Committee under Senator Lyndon B. Johnson had summarized its findings in 17 specific recommendations, including the establishment of an independent space agency.[8] During these months of debate and indecision, the military services continued their planning of space programs, both in hope of achieving a special role for themselves in space and in knowledge that U.S. planning could not simply stop during the months it took to settle the organizational problem.

Of the three military services the Air Force moved most rapidly with plans for advanced projects and programs. Responding to a request sent by the Office of the Secretary of Defense to the three military services, Headquarters USAF by mid-January 1958 had completed its review of the comprehensive five-year astronautics program submitted the previous month by the Air Research and Development Command. On January 24 the Air Force submitted the plan to William M. Holaday, Director of Guided Missiles in the Department of Defense. The five-year outline envisaged the development of reconnaissance, communications, and weather satellites; recoverable data capsules; a "manned capsule test system"; then manned space stations; and an eventual manned base on the Moon. The Air Force estimated that funding requirements for beginning such a long-range program in fiscal year 1959 would total more than $1.7 billion.[9]

The ambitious five-year plan, with its astronomical estimate of costs for the

coming fiscal year, had remained in Holaday's office. The Air Force pressed ahead with its astronautics plans, including the placing of a manned capsule in orbit. On January 29, 30, and 31, 1958, ARDC held a closed conference at Wright-Patterson Air Force Base near Dayton, Ohio, where 11 aircraft and missile firms outlined for Air Force and NACA observers the various classified proposals for a manned satellite vehicle that they had submitted to ARDC during November and December 1957. The industry presentations appear to have varied considerably in thoroughness and complexity. The Northrop Corporation, for example, simply reviewed the boost-glide concept suggested by NACA at the Round Three Conference the previous October and already adopted by the Air Force for its Dyna-Soar project. By contrast, the Avco Manufacturing Corporation, the McDonnell Aircraft Corporation, Republic Aviation, and North American Aviation made detailed presentations, including estimates of the minimum amount of time required to put a man in orbit. Like Avco and other firms, McDonnell of St. Louis had been working on designs for a "minimum" satellite vehicle, employing a pure ballistic shape, since the spring of 1956, when the Air Force had first briefed industry representatives on its original Manned Ballistic Rocket Research proposal. Republic sketched a triangular planform arrangement modeled on the vehicle suggested the previous year by Antonio Ferri and others at the Gruen Applied Science Laboratories.[10] The "Ferri sled," as the Republic device was called, was one of two approaches wherein the pilot would parachute after being ejected from the spacecraft, the vehicle itself not being recovered. The other company advocating an expendable spacecraft was North American; an X–15, although designed to land conventionally on skids as a rocket research aircraft, would orbit and then impact minus its parachuting pilot.[11]

After the Wright-Patterson conference, the Air Force stepped up the pace of its manned-satellite studies. On January 31, ARDC directed the Wright Air Development Center to focus on the quickest means of getting a man in orbit. The center was to receive advice from the Air Force Ballistic Missile Division in Los Angeles on selection of a booster system. A few weeks later the center issued a purchase request, valued at nearly $445,000, for a study of an internal ecological system that could sustain a man for 24 hours in an orbiting capsule.[12]

On February 27, ARDC officers briefed General Curtis E. LeMay, Air Force Vice Chief of Staff, on three alternative approaches to manned orbital flight: developing an advanced version of the X–15 that could reach orbital velocity; speeding up the Dyna-Soar project, which eventually was supposed to put a hypersonic glider in orbit; or boosting a relatively simple, nonlifting ballistic capsule into orbit with an existing missile system, as proposed by Avco, McDonnell, and other companies. LeMay instructed ARDC to make a choice and submit a detailed plan for an Air Force man-in-space program as soon as possible.[13]

While the Air Force pushed its manned satellite investigations and its development work on the Thor, Atlas, and Titan, the Army and the Navy initiated

manned space studies of their own in addition to accelerating their ballistic missile efforts with the Jupiter and the Polaris, respectively. Flushed with the success of the *Explorer I* satellite launching in January, the Army reached the apex of its astronautical prestige. Proud of the prowess of von Braun's rocket team at its Army Ballistic Missile Agency, Huntsville, Alabama, the Army sought a major role in military space technology. Since the Army already had lost operational responsibility for its Jupiter intermediate-range ballistic missile to the Air Force, a space mission was vitally important to its future in astronautics. Central to the Army's space plans was securing authorization, priority, and abundant financing from the Defense Department for one of von Braun's pet ideas, a clustered-engine booster vehicle with more than a million pounds of thrust.[14]

On February 7, 1958, Secretary of Defense Neil H. McElroy, acting on President Eisenhower's instructions, ordered the creation of an Advanced Research Project Agency (ARPA) to manage all existing space projects. Roy W. Johnson, a vice-president of General Electric, took over the directorship of this new office; Director of Guided Missiles Holaday transferred some of his responsibilities to the agency.[15]

Three weeks after the establishment of ARPA, Johnson acknowledged publicly that "the Air Force has a long term development responsibility for manned space flight capability with the primary objective of accomplishing satellite flight as soon as technology permits." The statement was reiterated on March 5 by a spokesman for McElroy. The Defense Department also authorized the Air Force to develop its "117L" system—an Atlas or Thor topped by a liquid-propellant upper stage (later named Agena) as a booster combination, together with an instrumented nose cone—"under the highest national priority in order to attain an initial operational capability at the earliest possible date." The 117L system, designed originally to orbit reconnaissance satellites, would now also be used for orbiting recoverable biological payloads, including primates.[16]

In response to Vice Chief of Staff LeMay's instructions of February 27 and the apparent receptiveness of Defense Department officials to the Air Force's astronautical plans, the Air Research and Development Command moved to "firm up" its plans for manned space flight. On March 8, the Ballistic Missile Division proposed an 11-step program aimed at the ultimate objective of "Manned Space Flight to the Moon and Return." The steps included instrumented and animal-carrying orbital missions, a manned orbit of Earth, circumnavigation of the Moon with instruments and then animals, instrumented hard and soft landings on the Moon, an animal landing on the Moon, manned lunar circumnavigation, and a manned landing on the lunar surface. Then, on March 10, 11, and 12, ARDC staged a large conference at the offices of its Ballistic Missile Division in Los Angeles. On hand were more than 80 rocket, aircraft, and human-factors specialists from the Air Force, industry, and NACA. Although the space sights of the Ballistic Missile Division, under Major General Bernard A. Schriever, were set on the

distant "man on the Moon" goal, the basic objective of the Los Angeles man-in-space working conference was to hammer out an "abbreviated development plan" for getting a man in Earth orbit as quickly and as easily as possible.[17]

The conference focused on what some Air Force speakers called a "quick and dirty" approach—orbital flight and recovery using a simple ballistic capsule and parachutes for a water landing in the vicinity of the Bahamas. The ballistic vehicle would weigh between 2700 and 3000 pounds, and would be about six feet in diameter and eight feet long. Its "life support," or internal ecological, system would be designed to sustain a man in orbit for as long as 48 hours. Because there was no real certainty that man could function under the various stresses of space flight, all systems in the capsule would be fully automatic.[18]

The human passenger would be essentially a rider rather than a pilot, although for experimental purposes he would try to perform certain tasks. The body support arrangement—showing the influence of Harold J. von Beckh of ARDC's Aeromedical Field Laboratory—would have the spaceman supine on a couch that could be rotated according to the direction of the g forces building up during launch and reentry. The rotatable couch was regarded as necessary because the capsule would both exit and enter the atmosphere front-end forward. Maximum reentry loads on the occupant of the Air Force machine were expected to be about 9 g; the interior temperature during reentry was not supposed to exceed 150 degrees. An ablative nose cone would provide thermal protection. Small retrograde rockets would brake the vehicle enough to allow the pull of gravity to effect a reentry.[19]

Among the most fervent Air Force champions of a man-in-space project at the Los Angeles conference were the human-factors experts, some of whom had been studying the medical problems of upper- and extra-atmospheric flight for more than a decade. But predictably they were also the most cautious people in assessing the psychophysiological limits of human tolerance under the conditions of flight into space. Air Force medical personnel generally agreed that 15 or more launches of primates and smaller biological payloads should precede the first manned orbital shot. Colonel John P. Stapp of the Aeromedical Field Laboratory felt that the first human space passengers should have both engineering and medical training, that they should go through at least six months of selection, testing, and preparation, and that from a medical standpoint a television camera was an essential piece of equipment in the manned capsule. Major David G. Simons, Stapp's colleague, believed that continuous medical monitoring of the man, including voice contact throughout the orbital mission, should be mandatory.[20]

The Air Force flight physicians knew that German centrifuge experiments during the Second World War had proved that men could withstand as much as 17 g for as long as 2 minutes without losing consciousness.[21] Nevertheless, numerous centrifuge runs at Wright-Patterson and at Johnsville, Pennsylvania, and calculations of the angle of entry from an orbital altitude of about 170 miles had convinced them that a 12-g maximum was a good ground rule for designing the capsule body-support system. With a continuously accelerating single-stage

booster following a steep launch trajectory, an aborted flight and subsequent reentry might subject the rider to as much as 20 g. Consequently the Air Force specialists assumed that a two-stage launch rocket would be necessary to provide a shallower reentry path and lower forces.[22]

In retrospect, there were two striking aspects of the Los Angeles man-in-space presentation. The first was that the Air Force, historically devoted to piloted, fully controllable aircraft, was thinking in terms of a completely automatic orbital capsule, virtually without aerodynamic controls, whose passenger would do little more than observe and carry out physiological exercises. The other was that no attention was given to using the Atlas alone as a booster system for a manned satellite. Indeed hardly anyone advocated putting an upper stage on the Atlas to constitute the desired two-stage launch vehicle. Spokesmen for Space Technology Laboratories, technical overseer of the Air Force ballistic missile program, went so far as to declare that a more dependable booster than the Atlas would have to be developed. They favored adapting the intermediate-range Thor and combining it with a second stage powered by a new fluorine-hydrazine engine developing some 15,000 pounds of thrust. By the time the conference adjourned on March 12, the conferees were in fairly general agreement that about 30 Thors and 20 fluorine-hydrazine second-stage rockets would be needed for a manned satellite project. Some 8 to 12 Vanguard second stages would also be needed, to be mated with Thors for orbiting smaller, animal-bearing capsules.[23]

While the "abbreviated development plan" was emerging from the Los Angeles gathering, a NACA steering committee met at the Ames laboratory. Its members were Hartley A. Soulé and John V. Becker of Langley, Alfred J. Eggers of Ames, and Walter C. Williams of the High Speed Flight Station. They had been appointed by NACA Assistant Director Ira H. Abbott to suggest a course of action on the January 31 proposal by Lieutenant General Donald L. Putt, Air Force Deputy Chief of Staff, Development, to NACA Director Dryden for formal NACA-Air Force cooperation in a manned satellite venture.[24] The steering committee agreed that the zero-lift approach—the ballistic capsule—offered the best promise for an early orbital mission. Soulé, Becker, Eggers, and Williams recommended that "NACA accept the Air Force invitation to participate in a joint development of a manned orbital vehicle on an expedited basis," and that "the ballistic type of vehicle should be developed." [25]

On March 14, a month and a half after Putt's letter to Dryden, NACA officially informed Headquarters USAF that it would cooperate in drawing up a detailed manned satellite development plan. On April 11, Dryden sent to General Thomas D. White, Chief of Staff of the Air Force, a proposed memorandum of understanding declaring an intention to set up a "joint project for a recoverable manned satellite test vehicle." Before a final agreement was actually signed, however, NACA Assistant Director for Research Management Clotaire Wood, at Dryden's direction, suggested to Colonel Donald H. Heaton of Headquarters USAF that the NACA-Air Force arrangement "should be put aside for the time

being." Heaton agreed, and in mid-May the joint Air Force-NACA manned space undertaking was tabled indefinitely.[26]

## NACA's Metamorphosis Begins

The explanation for Wood's action and for the general prudence of NACA in dealing with the Air Force on space matters in the spring of 1958 lay in the contents of the space bill sent by the Eisenhower administration to Capitol Hill on April 14 and then being debated in Congress. This proposal appeared likely to transform NACA into the focal point of the nation's efforts in space.

From the initial discussions in 1954 of a United States International Geophysical Year satellite project, President Eisenhower's position had been that space activities should be conducted solely for peaceful purposes. The nature and objectives of Project Vanguard had reflected this policy. He summed up his feelings in a letter to Soviet Premier Nikolai Bulganin, dated January 12, 1958. Describing the demilitarization of space as "the most important problem which faces the world today," he proposed that—

> . . . outer space should be used only for peaceful purposes. . . . can we not stop the production of such weapons which would use or, more accurately, misuse, outer space, now for the first time opening up as a field for man's exploration? Should not outer space be dedicated to the peaceful uses of mankind and denied to the purposes of war? . . .[27]

Consistent with this "space for peace" policy, the concentration on February 7, 1958, of Federal space activities in the Advanced Research Projects Agency of the Defense Department had been only an interim measure pending establishment of a new, civilian-controlled space management organization. Shortly before the creation of ARPA, Eisenhower had turned to his newly appointed, 18-member President's Scientific Advisory Committee (PSAC), chaired by President James R. Killian, Jr., of the Massachusetts Institute of Technology and including among its members NACA Chairman Doolittle. Eisenhower instructed the Committee to draw up two documents: a broad policy statement familiarizing Americans with space and justifying Government-financed astronautical ventures, and a recommendation for organizing a national program in space science. The "Killian committee," as the early PSAC was called, chose two subcommittees. One, on policy, was headed by Edward H. Purcell, a physicist and executive vice-president of Bell Telephone Laboratories; the other, on organization, was led by Harvard University physicist James B. Fisk.

The Fisk subcommittee on organization finished its work first. After talking with Doolittle and NACA Director Dryden, Fisk and his colleagues made a crucial report to PSAC late in February. A new agency built around NACA should be created to carry out a comprehensive national program in astronautics, emphasizing peaceful, civilian-controlled research and development. The White House Advisory Committee on Government Organization, consisting of Nelson B. Rocke-

feller, Killian, and Maurice H. Stans, Director of the Bureau of the Budget, used this PSAC subcommittee report as the basis for a formal recommendation on a national space organization, which Eisenhower received and approved on March 5. Five months after *Sputnik I*, the administration began drawing up proposed legislation for consideration by the Congress. As Dryden later observed, NACA's cautious post-Sputnik strategy had "paid off, in the long run."

PSAC's rationale for space exploration, entitled "Introduction to Outer Space," was issued on March 26. This statement proclaimed that "the compelling urge of man to explore and to discover," "the defense objective," "national prestige," and "new opportunities for scientific observation and experiment" were "four factors which give importance, urgency, and inevitability to the advancement of space technology." [28]

On April 2, Eisenhower sent his formal message on space matters to Congress. The document again indicated the President's intense conviction that space should be primarily reserved for scientific exploration, not military exploitation. It called for the establishment of a "National Aeronautical and Space Agency," which would absorb NACA and assume responsibility for all "space activities . . . except . . . those projects primarily associated with military requirements." The executive authority in the new organization would be exercised by one person, a director, who would be advised by a 17-member "National Aeronautical and Space Board." The proposal for a loose advisory board represented little more than an extension of the NACA Main Committee. The idea for a single executive, however, stemmed mainly from the opinions of Eisenhower's legislative experts and the officials of the Bureau of the Budget. They wanted authority in the new agency to be centralized, not diffused in a committee as was the case with NACA and the Atomic Energy Commission. The second and more critical departure from NACA history was Eisenhower's stipulation that the proposed organization would have not only research but development, managerial, and flight operational responsibilities. Unlike NACA, then, it would possess extensive authority for contracting research and development projects.[29]

Twelve days later, on April 14, the Eisenhower administration sent to the Democratic-controlled Congress its bill to create such an agency, drafted largely by the Bureau of the Budget.[30] In the House of Representatives and the Senate, special committees began hearings on the bill. The measure would undergo extensive amendment and reworking at the hands of the legislators. But it soon was apparent that a new agency would come into being, that NACA would constitute its nucleus, and that it would undertake large-scale development and operational activities in addition to research. The odds were better than good that a manned satellite project would fall within the domain of the civilian organization.

Proceeding on this assumption, engineers working at all of the NACA installations—at the ranges and wind tunnels at Langley and Ames, in the high-temperature jet facilities and rocket-test chambers at Lewis and Langley, at the



*NACA witnesses testify before the Senate Special Committee on Space and Astronautics, on May 6, 1958, with regard to bill S. 3609, "a bill to provide for research into problems of flight within and outside the earth's atmosphere, and for other purposes." The legislative end product would be the National Aeronautics and Space Act of 1958, which created NASA. NACA witnesses shown here: left to right, Paul G. Dembling, NACA Legal Adviser; James H. Doolittle, Chairman, NACA; and Abe Silverstein, Associate Director of NACA Lewis Flight Propulsion Laboratory.*

rocket launch pads and control panels on Wallops Island, and in the flight hangars at the High Speed Flight Station—stepped up their research in materials, aerodynamics, and control.[31] By early 1958, according to Preston R. Bassett, chairman of NACA's renamed Committee on Aircraft, Missile, and Spacecraft Aerodynamics, approximately 55 percent of all NACA activity was already applicable to space flight.[32] According to another set of NACA statistics, the Pilotless Aircraft Research Division (PARD) was expending 90 percent of its effort on space and missile research; the rest of the Langley laboratory, 40 percent; Ames, 29 percent; and Lewis, 36 percent.[33] Virtually every member of NACA's technical staff eagerly anticipated a national program of space exploration. Since the raison d'être of NACA always had been to improve the performance of piloted aircraft, most NACA engineers viewed manned space flight as an even more challenging and rewarding form of activity.

Not everyone in the NACA laboratories, however, was convinced that the agency's destiny lay in developing hardware, managing programs, and carrying out satellite launchings. Many scientist-engineers subscribed wholeheartedly to the official NACA position enunciated by Headquarters in January and February: While NACA ought to labor mightily in the furtherance of space science, it should continue to solve problems posed by other agencies engaged in development and operations, not handle programs itself. The "research-minded" element within the NACA technical staff probably was strongest at Ames. Most of the Ames complement had gone to work for NACA because of the nature of the organization. Its quasi-academic focus on research, its receptiveness to new and sometimes radical concepts, its relative obscurity and freedom from politics appealed to them. At the California institution the prospect of managing programs, which entailed fighting for appropriations, wrangling with industrial contractors, and perhaps competing with the military, seemed exceedingly distasteful.[34]

This attitude was not so prevalent at the two other laboratories or at the High Speed Flight Station. The years of direct participation with Air Force, Navy, and contract personnel in the research aircraft projects had given Walter Williams and his staff at the Flight Station a rather clear operational orientation, albeit with airplanes and not with space rockets and satellites. The Lewis and Langley staffs included a sizable number of research workers who, while enjoying the intellectual liberty of NACA, felt it would be quite a challenge to carry out a program of their own instead of simply providing advice for the military and industry. They looked on approvingly as the Eisenhower administration sent to Congress a measure substantially embodying their ideas.

The academic approach to aeronautics and astronautics pervaded much of Langley, the oldest and in some ways the most tradition-minded of the NACA laboratories. The commitment to basic research and the devotion to theoretical calculations and wind tunnels as the most efficacious means of gathering aerodynamic data were as strong among some Langley engineers as among the Ames investigators. But in the Flight Research, Instrument Research, and Pilotless Aircraft Research Divisions at Langley; at the semiautonomous Pilotless Aircraft Research Station on Wallops Island, 70 miles away across Chesapeake Bay; and in the Flight Research Division at Lewis, there were people who had gained the bulk of their experience by working with airfoils mounted on the wings of airplanes in flight and from air-launched and ground-launched scale models propelled by rockets. For years they had been close to "development" and "operations" in their research activities, but they had turned their telemetered findings over to someone else for practical application. Now it seemed that the Soviet artificial moons might have given these ambitious aeronautical engineers a chance to put their imagination and technical experience to use in a manned space flight program. As Paul E. Purser, then head of the High Temperature Branch of PARD, put it, "In early 1958 we simply assumed we would get the manned satellite project. So we started to work." [35]

Over the years the PARD specialists had perfected their techniques of launch, guidance, automatic control, and telemetry on small rockets, and had steadily added to the mountain of experimental data on hypervelocity performance and aerodynamic heating. Their rockets, while remaining small in thrust and payload, had become more and more sophisticated. During 1957, by firing five-stage research rockets, they had been able to achieve a final-stage velocity of mach 16.[36] And they already were doing conceptual work on a new and larger multistage research rocket, designed to boost scale models in their own stability and heat-transfer studies and to send up small instrumented satellites and space probes for the Air Force. Later called the Scout, this four- or five-stage, solid-propellant configuration could fire its stages sequentially to place either a 150-pound payload in a 300-mile orbit, 100 pounds in a 5000-to-10,000-mile orbit, or 30 pounds in an orbit more than 22,000 miles from Earth.[37]

In the hectic weeks and months following the Soviet satellite launchings, the advocates of manned space flight at Langley, realizing that their experience in nose-cone research was directly transferable to the design of manned satellite vehicles, turned their attention to spacecraft design as never before. NACA's initial agreement of March 14, 1958, to collaborate with the Air Force in drawing up plans for a manned orbital project gave official sanction to research they already had been doing largely on their own time. Theoretically this work still was in support of the Air Force and industrial manned-satellite studies. As it turned out, the Langley engineers were doing the early development work for their own enterprise, later to become Project Mercury.

The sparkplug behind much of this activity was Maxime A. Faget, head of the Performance Aerodynamics Branch in PARD. Thirty-seven years old in 1958, Faget had been born in British Honduras, the son of an honored physician in the United States Public Health Service. In 1943, when his father was developing sulfone drugs for the National Leprosarium in Carville, Louisiana, the diminutive Faget received a bachelor of science degree in mechanical engineering from Louisiana State University. After his discharge from the Navy's submarine service in 1946, he joined the staff at Langley. He soon devised choking inlets for ramjets, a flight mach number meter, and several mathematical formulas for deriving data from Richard T. Whitcomb's area rule.[38] Like Robert R. Gilruth and others before him at Langley, Faget preferred to enlarge his knowledge in aerodynamics and thermodynamics not in wind tunnels but by observing and telemetering data from vehicles in free flight.

In mid-March, less than a week after the conclusion of the Air Force man-in-space working conference in Los Angeles, Gilruth, as Assistant Director of Langley, called Faget and his other top engineers together to determine what should be the "Langley position" on optimum spacecraft configurations at the NACA Conference on High-Speed Aerodynamics, to be held at the Ames laboratory beginning March 18. The consensus of the meeting was that the Langley-PARD representatives should present a united front at Ames behind a ballistic concept.[39]

The Conference on High-Speed Aerodynamics, the last in a long line of full-dress symposiums held by NACA, attracted most of the luminaries in the organization, including Dryden, Silverstein, Eggers, H. Julian Allen, Walter Williams, and the members of the Committee on Aircraft, Missile, and Spacecraft Aerodynamics. Military personnel and representatives of most of the aircraft and missile firms also attended this forum. The 46 papers read at the conference, dealing with hypersonic, satellite, and interplanetary flight, represented the most advanced thinking in aerodynamics within NACA. Taken together, the papers demonstrated how far some NACA engineers trained in aeronautics had pushed their research into the new discipline of astronautics.[40]

Much interest centered around three presentations proposing alternative configurations for manned orbital flight. The first of these papers was authored by Faget, Benjamine J. Garland, and James J. Buglia. Faget presented it as the orbital configuration regarded most favorably by PARD personnel—the wingless, nonlifting vehicle. Faget and his associates pointed out several advantages of this simple ballistic approach. In the first place, ballistic missile research, development, and production experience was directly applicable to the design and construction of such a vehicle. The fact that it would be fired along a ballistic path meant that automatic stabilization, guidance, and control equipment could be kept at a minimum, thus saving weight and diminishing the likelihood of a malfunction.

The nonlifting vehicle simplified return from orbit because the only necessary maneuver was the firing of retrograde rockets—"retrorockets"—to decelerate the spacecraft, deflecting it from orbit and subjecting it to atmospheric drag. And even that maneuver need not be too precise for the accomplishment of a safe recovery. After retrofire, successful entry depended solely on the inherent stability and structural soundness of the ballistic vehicle. Faget, Garland, and Buglia acknowledged that the pure-drag device necessitated landing in a large and imprecisely defined area, using a parachute, and dispensing with lifting and braking controls to correct the rate of descent, the direction, or the impact force. Rather severe oscillations might occur during descent. But Faget and his associates noted that tests with model ballistic capsules in the 20-foot-diameter, free-spinning tunnel at Langley had shown that attitude control jets, such as those used on the X–1B, X–2, and X–15 rocketplanes, could provide rate damping and help correct the oscillations, while a small drogue parachute should give still more stability.

The three Langley engineers went so far as to propose a specific, if rudimentary, ballistic configuration—a nearly flat-faced cone angled about 15 degrees from the vertical, 11 feet long and 7 feet in diameter, using a heat sink rather than an ablative covering for thermal protection. Although the space passenger would lie supine against the heatshield at all times, during orbital flight the capsule would reverse its attitude so that the deceleration loads of reentry would be imposed from front to back through the man's body, the same as under



*Once the basic Mercury spacecraft configuration had been decided, aerodynamic research turned to the further problems generated by associated equipment, such as the escape tower and the landing parachute. At left is a model of the spacecraft with launch escape tower being prepared for test in the free-flight tunnel at Langley in 1959. Another scale model was fitted with a drogue parachute (below) and tested for stability during descent in Langley's vertical wind tunnel.*



acceleration. The authors concluded that "as far as reentry and recovery is concerned [sic], the state-of-the-art is sufficiently advanced so that it is possible to proceed confidently with a manned satellite project based upon the ballistic reentry type of vehicle." [41]

One dissenter from the Langley consensus favoring a manned projectile was John Becker, of the Langley Compressibility Research Division and a veteran of X–15 development, who read a paper at the conference on possible winged satellite configurations. Becker's main concern was the reentry heating problem in conjunction with some maneuverability within the atmosphere. Combining his theoretical findings with those of Charles W. Mathews of Langley, Becker suggested a glider-like configuration. Instead of entering the atmosphere at a low angle of attack and using lift to return to Earth, it would deliberately come in at a high angle of attack, employing its lower wing surface as a heatshield. Deceleration loads still could be held at a little over 1 g in this fashion. The gross weight of such a low-lift, high-drag vehicle would be only about 3060 pounds. "Thus . . . the minimum winged satellite vehicle is not prohibitively heavier than the drag type," concluded Becker. "The weight is sufficiently low to permit launching by booster systems similar to that for the drag vehicle described in a previous paper by Maxime A. Faget, Benjamine J. Garland, and James J. Buglia." [42]

What some Langley researchers had come to regard as the "Ames position" on manned satellites was described in a paper by Thomas J. Wong, Charles A. Hermach, John O. Reller, and Bruce E. Tinling, four aeronautical engineers who had worked with Eggers. They presented a polished, more detailed version of the blunt, semilifting M–1 configuration conceived by Eggers the previous summer. For such a vehicle a lift/drag ratio of ½ could be effected simply by removing the upper portion of a pure ballistic shape, making the body somewhat deeper than that of a half-cone, and adding trailing edge flaps for longitudinal and lateral control. Maximum deceleration forces would be only 2 g, low enough to permit a pilot to remain in control of his vehicle. Blunting would reduce heat conduction; the vehicle would be stable and controllable down to subsonic speeds and would provide substantial maneuverability; and structural weight would remain relatively low. Thus "it appears that a high-lift, high-drag configuration of the type discussed has attractive possibilities for the reentry of a satellite vehicle." [43]

The Ames engineers' presentation was not in the form of a spacecraft design challenge to the Langley-PARD aerodynamicists. Eggers and various others at Ames remained convinced of the overall superiority of the lifting body for manned satellite missions. But as Eggers explained, "Ames was not enthusiastic in 1958 to participate in an operational program for building and launching spacecraft of any kind, manned or unmanned." [44] While some Ames people were rather avidly pushing the M–1 concept, their avidity did not stem from any desire for operational dominance in a civilian space program. The Cali-

fornia NACA scientists were quite willing to leave the business of building prototypes, carrying out full-scale tests, and then managing a program to their more "hardware-oriented" colleagues across the continent.

To Faget, Purser, and Gilruth the choice between the semilifting configuration favored by the Ames group and their nonlifting device really was an academic one. Given the assumption that a manned satellite should be fired into orbit as quickly as possible, then the Atlas ICBM, not the still untested Titan or a Thor-fluorine combination, should serve as the launch vehicle for a one-ton spacecraft. The Atlas was following a tortuous route toward status as a reliable operational rocket, but it was still the only ICBM anywhere near being ready. The criterion already adopted by Faget and his associates, that an attempt to orbit a man should follow the simplest, quickest, and most dependable approach, negated a heavier, semilifting vehicle; this would have required adding an extra stage to the Atlas or some other rocket. The same criterion even ruled out Becker's low-lift, high-drag proposal. If the first manned orbital project was to adhere to and profit from ballistic missile experience, then the capabilities of the Atlas should be the first consideration. Faget himself did not have detailed data on the Atlas' design performance before, during, or for some time after the Ames conference; such information was highly classified and he lacked an official "need to know." About two months after he delivered his paper he learned through conversations with Frank J. Dore, an engineer-executive of Convair, what he needed to design a manned ballistic payload.[45] In the weeks following the Ames conference, Faget's and other Langley-PARD research teams, centering their efforts on the basic ballistic shape, started working out the details of hurling a man-carrying projectile around the world.[46]

While the engineers at the NACA Virginia installations hurried their designs, tests, and plans, and while Congress received Eisenhower's space bill, the organizational transformation of NACA began. After the White House Advisory Committee on Government Organization recommended that a national civilian space program be built around NACA, Director Dryden and his subordinates in Washington began planning the revamping that would have to accompany the reorientation of NACA functions. Dryden called Abe Silverstein of Lewis to Washington to begin organizing a space flight development program. On April 2, as part of his space message to Congress, Eisenhower instructed NACA and the Defense Department to review the projects then under ARPA to determine which should be transferred to the new civilian space agency. NACA and Defense Department representatives, in consultation with Bureau of the Budget officials, reached tentative agreements on the disposition of practically all the projects and facilities in question, with the notable exception of manned space flight. In accordance with Eisenhower's directive that NACA "describe the internal organization, management structure, staff, facilities, and funds which will be required," NACA set up an ad hoc committee on organization under the chairmanship of Assistant Director Ira Abbott.[47]

## Man in Space Soonest?

Officially NACA still was acting as consultant and tester for the Air Force and industry on spacecraft design and development. ARDC had sent its abbreviated development plan for a manned orbital capsule, based on conclusions reached at the Ballistic Missile Division conference, to Headquarters USAF on March 14. Five days later Air Force Under Secretary Marvin A. MacIntyre requested $133 million from ARPA for manned satellite development during fiscal year 1959. On the same day that Eisenhower proposed the civilian agency to Congress, General White, Air Force Chief of Staff, secured approval for a man-in-space project from the Joint Chiefs of Staff. Despite the introduction of the administration bill in Congress and the resultant tabling the next month of the proposed agreement between White and Hugh Dryden for a joint Air Force-NACA manned satellite project, NACA continued to furnish advice and information to the Air Force.[48]

Throughout most of April, representatives from the various offices within ARDC, forming a "Man-in-Space Task Force" at the Ballistic Missile Division, worked on an "Air Force Manned Military Space System Development Plan." The final goal was to "achieve an early capability to land a man on the moon and return him safely to earth." The first of four phases, called "Man-in-Space-Soonest," involved orbiting a ballistic capsule, first carrying instruments, then primates, and finally a man. In the second phase, "Man-in-Space-Sophisticated," a heavier capsule, capable of a 14-day flight, would be put in orbit. "Lunar Reconnaissance," the third phase, would soft-land on the Moon with instruments, including a television camera. The last phase was "Manned Lunar Landing and Return," wherein primates, then men, would be orbited around the Moon, landed on its surface, and returned safely. The whole undertaking was supposed to cost $1.5 billion, a level of financial support that should complete the program by the end of 1965. The Thor-Vanguard, the Thor with a fluorine upper stage, and a "Super Titan" topped by fluorine second and third stages would be the launch vehicles.[49]

The detailed designs and procedures for the Man-in-Space-Soonest portion of the long-range program went to Headquarters USAF on May 2. Based on Thor-117L, Thor-Vanguard, and Thor-fluorine booster combinations, the "Soonest" concept posited a manned orbit of Earth on the tenth launch of the Thor-fluorine system, in October 1960.[50]

Meanwhile, on April 30, the contractor team of Avco and Convair, which, since the Sputniks, had spent more time and money on manned satellite design than other industrial firms, presented to the Air Force a highly detailed proposal for development of a "minimum" vehicle. Featuring the "bare" Atlas, the basic "one and one-half stage" ICBM with no second stage, the Avco-Convair approach would orbit a man inside a sphere weighing 1500–2000 pounds. The steel-mesh drag brake, a metallic, inverted parachute, would be used for atmospheric entry.[51]

Specialists at the Ballistic Missile Division concluded that using the "bare" Atlas would save only three or four months of development time, that it would necessitate an undesirably low orbital altitude, that it ignored the prospect of dangerously high reentry g forces following an "abort" with what was essentially a single-stage booster, and that it presented little "growth potential," in contrast to the Thor-fluorine system.[52] As early as March, moreover, ARDC's advisers in NACA, led by Maxime Faget, had criticized the complex drag-brake apparatus as "poor policy that might interfere with the early completion of the program as well as being a totally unnecessary device." [53]

However, Air Force Vice Chief of Staff LeMay, whose directive back in February had accelerated the proposed military manned satellite project, now ordered a reevaluation of the Avco-Convair scheme. LeMay felt this was possibly a cheaper way to get a man into space than Man-in-Space-Soonest, which called for an expenditure of more than $100 million for fiscal 1959. On May 20, Lieutenant General Samuel E. Anderson, Commander of ARDC, replied that in view of a general lack of confidence within ARDC in the Avco metal shuttlecock device, the Air Force should pursue the Man-in-Space-Soonest approach. LeMay accepted this recommendation.[54] Henceforth, although there would be significant amendments to Man-in-Space-Soonest, the Air Force's own plan would encounter diminishing competition from would-be contractors' alternatives.

While Anderson was discouraging LeMay's interest in the Avco-Convair proposal, General Schriever, Commander of the Ballistic Missile Division, wrote Anderson that his office was ready to proceed with a manned orbital project; the selection of a capsule contractor awaited only allocation of sufficient funds. But ARDC still could not secure full authorization from the Advanced Research Projects Agency, under which the Air Force would have to fund a project to put a man in orbit. ARPA had sketched the Soonest plan before the National Security Council Planning Board, which supposedly had a "feeling of great urgency to achieve . . . Man-in-Space-Soonest at the earliest possible date." But ARPA Director Johnson still shrank from the initial $100-million-plus request contained in the program outline.[55]

The main trouble was the high cost of mating the intermediate-range Thor with 117L and Vanguard second stages, developing an entirely new rocket with a fluorine powerplant, and carrying out perhaps as many as 30 development flights before trying to orbit a manned capsule.[56] Late in May, Air Force Under Secretary MacIntyre and Assistant Secretary Richard E. Horner suggested that making the Atlas a carrier for manned flight might cut program costs below the $100 million mark. ARDC then had its Ballistic Missile Division prepare an alternative approach for Man-in-Space-Soonest. The BMD answer was that using the Atlas would mean reducing the orbital altitude of the 2000–3000-pound capsule from about 170 miles to about 115 miles. This in turn would mean that voice contact would be lost for long periods unless more orbital tracking stations were built around the globe. Despite these reservations, on June 15, the Ballistic

Missile Division sent to Washington a revised development plan for orbiting a man in an Atlas-boosted ballistic capsule by April 1960 at a total cost of $99.3 million. The next day ARPA gave its approval to the revised "Soonest" plan and authorized the Air Force to proceed with study contracts on the life support system of the proposed manned capsule. The Wright Air Development Center let two concurrent three-month study contracts, at $370,000 each, to North American Aviation and General Electric, which were to design the space cabin and ecological mechanisms and build "mockups"—full-scale working models—of the capsule interior.[57]

By late June, with the reworked version of the space bill proposed by the Eisenhower administration almost ready to be voted on in Congress, it was apparent that the Air Force was in much more of a hurry to hurl a man into orbit than was ARPA. The new Defense Department agency remained reluctant to commit heavy financing to a project that might well be abandoned or transferred when the civilian space organization proposed by Eisenhower came into existence. Throughout June and into July, an ARPA Man in Space Panel, headed by Samuel B. Batdorf, received briefings and proposals from the Air Force and in turn reported to Herbert F. York, chief scientist in ARPA. But during these weeks Faget, serving as the regular NACA representative on the ARPA panel, began to detect a definite change in the attitude of ARPA personnel toward NACA. The essence of this change, according to Faget, was the growing belief that now perhaps ARPA should give more advice to NACA on space technology than vice versa, as had been the case. For example, York recommended to Johnson that NACA Director Dryden's "personal concurrence" be obtained before any Air Force man-in-space program was formally approved by ARPA.[58]

On June 25 and 26, the ARPA Man in Space Panel sponsored a meeting in Washington for representatives from Headquarters ARDC, the Ballistic Missile Division, Convair, Lockheed, Space Technology Laboratories, and NACA. The meeting was called to resolve such outstanding questions as the relationship between payload weight and the lifting capabilities of various booster systems, booster reliability, and ablation versus heat sink thermal protection techniques. The gathering produced little specific technical agreement. Into July, ARPA continued to hold back adequate "go-ahead" funds for a full-fledged Air Force effort to send a manned vehicle into orbit.[59]

## NACA Makes Ready

Throughout the spring and into the summer of 1958, as the administration bill made its way through Congress, NACA had given its full participation and support to the man-in-space planning sessions of ARPA and the Air Force. But at the same time the research engineers at Langley and on Wallops Island were pushing their own studies. They could see the opportunity to carry out a manned

satellite project coming their way. By early spring all NACA laboratories were urgently engaged in basic studies in such areas as propulsion, spacecraft configuration, orbit and recovery, guidance and control, structures and materials, instrumentation, and aerodynamic heating. Ames and Langley researchers were conducting wind tunnel experiments and rocket launches with models of orbital vehicles.[60]

At the Langley laboratory, proponents and would-be managers of a manned space flight program studied the nonlifting approach to orbital circumnavigation, refined this concept, tested it, restudied it, and invented new ways to prove hardware feasibility and reliability. Floyd L. Thompson, Associate Director of Langley and Acting Director most of the time, gave Robert Gilruth the go-ahead for manned satellite work. In turn, Gilruth gave a free hand to PARD Chief Joseph A. Shortal, Faget, Purser, Charles Mathews, Alan B. Kehlet, Willard S. Blanchard, Jr., Carl A. Sandahl, and others at the Virginia laboratory.[61]

The search for better experimental methods in manned satellite research produced a concept by Purser and Faget for a new test rocket which would employ a cluster of four solid-propellant Sergeant rockets to provide a high initial thrust. Fired almost vertically and unguided except for large stabilizing aerodynamic fins, the rocket would be an inexpensive means of testing full-scale models of spacecraft in the most critical phases of an orbital mission—launch, abort, and escape at different speeds and under different stresses, parachute deployment, and recovery. Such a vehicle could also "toss" a man in a ballistic capsule to an altitude of perhaps 100 miles. Late in February, Purser and Faget received a job order and authorization to proceed with design work on the test rocket, which at that time they called "High Ride." [62]

Another experimental technique devised by the PARD engineers was a full-scale "capsule simulator." It was designed to test the practicability of controlling the attitude of a ballistic vehicle manually by activating air jets mounted on its body, similar to the method that would be used to control the X–15 at the peak of its trajectory. In March, Purser and several others in PARD put into operation a crude simulator rig featuring a small bed covered by a tent and attached to a pendulum. The pendulum permitted an oscillation period of two to four seconds, during which the "pilot" attempted to realign the simulator by firing the air jets. Throughout the spring Langley test pilot Robert A. Champine, Purser, and others took turns riding the simulator. Frequently modified and improved, it provided useful data on spacecraft reaction controls.[63]

Meanwhile Faget and his coworkers were steadily modifying the manned ballistic satellite design itself. Almost from the beginning of their design studies and tests, late in 1957, they had assumed that a ballistic vehicle should enter the atmosphere at an attitude 180 degrees from that of launch, so the g forces would be imposed on the front of the body under both acceleration and deceleration. The "tail" of the capsule when it went into orbit would become its "nose" during reentry. Their original capsule configuration—a squat, domed body with a nearly

flat heatshield—resembled the Mark II missile warhead. The body was recessed slightly from the perimeter of the heatshield, leaving a narrow lip that theoretically would deflect the airflow in such a way as to minimize heat transfer to the after portion. But models of this configuration tested in the Langley free-spinning tunnel proved dynamically unstable at subsonic speeds. The Faget group then lengthened the capsule fuselage and eliminated the heatshield lip. By March 1958, the Langley ballistic vehicle, as described by Faget, Garland, and Buglia at the Ames Conference on High-Speed Aerodynamics, was an elongated cone. This design contrasted sharply with the configuration sketched earlier that month at the ARDC working conference in Los Angeles—a rather deep dome, the rounded front end of which was the heatshield.[64]

The elongated cone provided dynamic stability during the blazing period of reentry, but tests in the 11-inch hypersonic tunnel and other tunnels at Langley showed that too much heat would be transferred by turbulent convection to its afterbody. Besides thermodynamic considerations, the NACA planners could not figure out how to fit into the top part of the cone the two parachutes necessary for its recovery. The Virginia designers next tried a conical nose shape, then a rounded one with a short cylinder attached to it, but the problems of heat transfer from the heatshield and insufficient space for parachute packaging remained for both of these configurations. It was late summer 1958 before the Langley-PARD researchers had settled on a capsule design combining the advantages of maximum stability in a nonlifting body, relatively low afterbody heating, and a suitable parachute compartment. This was the shape that became the basis of the Mercury spacecraft—a blunt face, a frustum, or truncated cone, and a cylinder mounted atop the frustum. The completely flat heatshield had been discarded because it trapped too much heat, while a rounded face only increased heat transfer. The design ultimately chosen featured a heatshield with a diameter of 80 inches, a radius of curvature of 120 inches, and a ratio of 1.5 between the radius of the curve and the diameter of the shield.[65] This heatshield design, as worked out by William E. Stoney, Jr., of PARD at Langley, and confirmed by Alvin Seiff, Thomas N. Canning, and other members of the Vehicle Environment Division at Ames, got rid of a maximum amount of heat during reentry.[66]

Materials research continued at Langley throughout the spring and summer. In their man-in-space development plans, the Air Force experts initially had favored an ablation heatshield, but their NACA advisers generally felt that the ablation technique was not yet reliable enough for manned reentry. In March, two of the most respected engineers in the NACA establishment, Gilruth and Soulé of Langley, assisted by Clotaire Wood of Headquarters, had presented to the Air Research and Development Command NACA's design concepts for manned orbital flight, including use of the heat sink on a blunt body as the best thermal protection procedure. The question remained open, however. In June, the Wright Air Development Center, the Ballistic Missile Division, and NACA agreed to undertake joint investigation of heatshield materials, the objective being

to compile a sufficient quantity of data for ARDC to make a decision between heat sink and ablation methods within three months.[67]

Considering the unreliability common in early ballistic missiles, and especially the widespread lack of confidence in the hard-pushed Atlas, some fast and almost foolproof means of escape would be essential to any launch system for manned space flight. The Air Force man-in-space designs had included an escape mechanism with many moving parts and a degree of complexity unacceptable to the NACA engineers. The Air Force plans envisioned a pusher rocket escape system, meaning that a rocket or rockets would fire at the base of the capsule to hurl it clear of the booster. The PARD rocket experts, again led by Faget, rejected this approach and began working on a solid-fueled tractor escape rocket. This would be mounted above the capsule and would pull it upward and away from a faulty launch vehicle. By the end of August 1958, Willard Blanchard and Sherwood Hoffman of PARD, working on plans and suggestions hurriedly made by Faget and Andre J. Meyer, Jr., had drawn designs for the escape rocket and tower, consisting of a slender rocket case and nozzle and three thin struts fastened to the cylinder of the capsule. The Wallops Island engineers already were planning a series of test firings of the awkward-looking escape mechanism, using "boilerplate" capsules, or full-scale metal models.[68]

The solid-fueled tractor rocket with a minimum of components reflected the Langley-PARD preoccupation with the easiest, most dependable way to get a manned spacecraft into orbit. There were certain interlocking aspects of the approach. The "bare" Atlas, the regular ICBM without an upper stage, should be the booster. With the ballistic capsule, acceleration forces during launch would be about 5 or 6 g; on a shallow reentry trajectory, deceleration loads should not exceed 8 or 9 g. But an abort and reentry after a launch following the steep trajectory and unbroken acceleration of a single-stage booster could impose as much as 20 times the force of gravity on the capsule passenger. Air Force planners had considered a two-stage booster and a flight profile with a more shallow trajectory, or a variable-drag device like the Avco metal parachute, to lessen the abort-reentry g loads—although by midsummer cost considerations were pushing the Air Force toward the bare Atlas.[69] For body support, the Air Force had thought in terms of some kind of rotational apparatus to maintain continuously optimum positioning in relation to the direction of acceleration.[70] This procedure, the NACA engineers felt, was too complicated and probably entailed too much weight.

As Man-in-Space-Soonest was taking shape in late spring, featuring a two-stage booster and either a rotatable interior cabin or a rotatable couch, Faget had another idea. Why not build a lightweight, stationary couch that a man would lie not on but in? This was the fundamental principle behind the contour couch designed by Faget, fabricated out of fiber glass at Langley, and tested on the big Navy centrifuge at Johnsville late in July.[71] There, in what Faget called "the only technical 'break-through' of the summer," Carter C. Collins and R. Flanagan

Gray of the Navy endured more than 20 g while riding in the contour couch. Then, said Faget, "we were able to disregard the USAF 'ground rule' (and a rather firmly established one in their minds) that 12 g was the reentry design limit." The bare Atlas could be used to hurl a man into orbit, and an abort need not impair his safety.[72]

## Birth of NASA

Even before the contour couch was demonstrated, the Air Force research and development planners also had about accepted the bare Atlas as a manned satellite booster, although they retained serious misgivings regarding abort and reentry g loads, orbital altitude, lifting ability, and reliability. But by early July 1958, there actually seemed to be an inverse relationship between the Air Force's progress on Man-in-Space-Soonest and the progress of the space bill through Congress. On July 10, Brigadier General Homer A. Boushey of Headquarters USAF informed the Air Research and Development Command that the Bureau of the Budget was firmly in favor of placing the space exploration program, including manned space flight, in the proposed civilian space organization. Nothing could be done to release further go-ahead funds from the Advanced Research Projects Agency.[73]

Only a little more than three months after the Eisenhower administration's draft legislation went to the Capitol, both houses of Congress on July 16 passed the National Aeronautics and Space Act of 1958, creating the National Aeronautics and Space Administration. Despite this long-expected action, there still seemed to be a chance for Man-in-Space-Soonest, provided it could be carried out at a relatively modest cost. So Roy Johnson and his subordinates in ARPA continued to admonish the Air Force to scale down its funding requests. The Ballistic Missile Division replied that a fiscal 1959 budgetary allotment of only $50 million, the latest figure suggested by ARPA, would delay the first manned orbital launch until late 1961 or early 1962. In its sixth development plan for Man-in-Space-Soonest, issued on July 24, BMD proposed orbiting a man by June 1960 with the bare Atlas, at a cost of $106.6 million. This was an increase of $7.3 million over the project cost estimate contained in the fifth development plan on June 15. Schriever personally wrote Anderson, Commander of ARDC, that the Ballistic Missile Division was already studying requirements for a world-wide tracking network, that the heat sink versus ablation question was under examination, that three companies were designing the 117L and the Vanguard second stage as possible backup systems for the bare Atlas, and that invitations for a briefing for prospective capsule contractors could be mailed within 24 hours. Schriever asked for immediate approval for Man-in-Space-Soonest at the $106.6 million level.[74]

In Washington, on July 24 and 25, Ballistic Missile Division specialists gave a series of briefings for ARDC, Secretary of the Air Force Douglas, the Air Staff, and ARPA. The ARPA briefing featured urgent appeals for full, immediate program approval to give the United States a real chance to be "soonest" with a

man in space. ARPA Director Johnson flatly refused to give his go-ahead at that time. President Eisenhower and his advisers, he explained, were convinced there was then no valid role for the military in manned space flight. NACA, the nucleus of the civilian space program to be organized under the terms of the recently passed Space Act, already was planning its own manned satellite project, perhaps to be executed in conjunction with ARPA, at a cost of about $40 million for fiscal 1959. Consequently, said Johnson, it was futile for the Air Force to expect more than $50 million for the current fiscal year for Man-in-Space-Soonest. The implication was the Air Force would be lucky to receive even that.[75]

Eisenhower signed the National Aeronautics and Space Act into law on July 29, 1958. His action brought into being an organization to "plan, direct, and conduct aeronautical and space activities," to "arrange for participation by the scientific community in planning scientific measurements and observations," and to "provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof"—in short, to guide the Nation into the Space Age.[76] Space activities related to defense were to continue in the DOD.

There were certain basic differences between the final act and the bill that representatives of NACA, the Bureau of the Budget, and Eisenhower's other advisers had drafted and sent to Congress in April. These changes were the product especially of the activities and influence of three men: Lyndon B. Johnson, Senate majority leader and chairman of the Preparedness Subcommittee of the Senate Committee on Armed Services and the Senate Special Committee on Space and Astronautics; John W. McCormack, House majority leader and chairman of the House Select Committee on Astronautics and Space Exploration; and Senate minority leader Styles Bridges of New Hampshire, ranking Republican on the Senate space committee.[77]

The large Space Board proposed by the administration to advise the head of the civilian agency gave way to a five-to-nine-member National Aeronautics and Space Council, charged with advising the President, who was to be its chairman. The provision for a National Aeronautics and Space Administration, headed by an administrator and a deputy administrator, rather than a "Space Agency" headed by a single director was, according to two staff members of the House space committee, "a mighty promotion in Washington bureaucratic terms." [78] Reflecting general concern in Congress over the relationship between space technology and national defense, the Space Act added a Civilian-Military Liaison Committee, appointed by the President, to ensure full interchange of information and data acquired in NASA and Defense Department programs. Other significant amendments pertained to patent procedures, authority to hire some 260 persons excepted from the civil service rating system, and NASA's obligation to cooperate with "other nations and groups of nations." [79]

Eisenhower, acting mainly on the advice of Killian, his chief scientific adviser, passed over the respected, apolitical Dryden, Director of NACA since 1949, and named T. Keith Glennan, president of the Case Institute of Technology in Cleve-

land, former member of the Atomic Energy Commission, and a staunch Republican, as the first Administrator of NASA. Dryden was appointed to the post of Deputy Administrator. Glennan would furnish the administrative leadership for the new entity, while Dryden would function as NASA's scientific and technical overseer. On August 15 the Senate voted its confirmation of Glennan and Dryden, and four days later the new Administrator met with the Abbott organization committee to review the proposed organization of NASA.[80]

The National Aeronautics and Space Administration, absorbing more than 8000 employees and an appropriation of over $100 million from NACA, was beginning to take shape. Under the terms of the Space Act, accompanying White House directives, and later agreements with the Defense Department, the fledgling agency acquired the Vanguard project from the Naval Research Laboratory; the Explorer project and other space activities at the Army Ballistic Missile Agency (but not the von Braun rocket group); the services of the Jet Propulsion Laboratory, hitherto an Army contractor; and an Air Force study contract with North American for a million-pound-thrust engine, plus other Air Force rocket engine projects and instrumented satellite studies. In addition, NASA was to receive $117 million in appropriations for space ventures from the Defense Department.[81] But the Space Act was silent regarding organizational responsibility for manned space flight.

## Other Means to the Same End

Besides Man-in-Space-Soonest of the Air Force, there were two other manned military space ventures seeking approval from ARPA in the summer of 1958. A rather heated competition was underway among the three armed services in the area of manned space flight. The Army's entry, much simpler than the Air Force approach, was supposed to lift a man into the space region "sooner" than Soonest. After the Sputniks, von Braun and his colleagues at Redstone Arsenal had had great success resuscitating their instrumented satellite project. Now they had unearthed one of their old proposals for using a modified Redstone to launch a man in a sealed capsule along a steep ballistic, or suborbital, trajectory. The manned capsule would reach an altitude of approximately 150 miles before splashing into the Atlantic about the same distance downrange from Cape Canaveral. The passive passenger would be housed in an ejectable cylindrical compartment about four feet wide by six feet long, which in turn would be housed in an inverted version of the kind of nose cone used on the Jupiter IRBM.[82]

The Army tried to justify the proposal partly as a step toward improving techniques of troop transportation. But, more important, such a ballistic shot supposedly could be carried out during 1959; this would recoup some of the prestige captured by the Soviet satellite launchings as well as furnish some much-needed medical information, especially regarding high g loading and the effect of about six minutes of weightlessness. Initially called "Man Very High," the

project called for the support of all three services. The sealed compartment would be modeled closely on the Air Force Manhigh balloon gondola then being used in a series of record-breaking ascents. In April the Air Force, already overloaded with plans for its own Dyna-Soar and manned satellite projects, had decided not to participate. So the Army had renamed the plan "Project Adam" and had begun pushing it as an Army project, with Navy cooperation expected in the medical and recovery phases.[83]

The Adam proposal began the formal climb from the Army Ballistic Missile Agency through the Pentagon hierarchy to the office of the Secretary of the Army, then to ARPA. It came under very heavy criticism from sources both inside and outside the Defense Department. The ARPA Man in Space Panel unequivocally recommended that the proposal be turned down. Hugh Dryden of NACA told the House Space Committee that "tossing a man up in the air and letting him come back . . . is about the same technical value as the circus stunt of shooting a young lady from a cannon. . . ." And Arthur Kantrowitz of Avco, whose company was still trying to get the Air Force manned satellite contract, termed Adam "another project which is off the main track because I feel that weightlessness is not that great a problem." [84]

On July 11, ARPA Director Johnson notified Secretary of the Army Wilbur M. Brucker that ARPA did not consider Project Adam a practical proposal for manned space flight. Consequently the Army could not expect to receive the $10–12 million it requested for the "up-and-down" project. Early in August, Brucker, mentioning that the Central Intelligence Agency had expressed an interest in Adam, defended the approach as a potential "national political-psychological demonstration." Deputy Secretary of Defense Donald A. Quarles replied that in light of the Soviet achievement of orbiting an animal, the Air Force man-in-space project, and the creation of NASA, a decision on Project Adam would have to await "further study." In succeeding months the controversial "lady from a cannon" plan slipped quietly into the inactive category at Redstone Arsenal.[85]

Still a third military proposal for manned space flight came forth during the contentious first half of 1958. In April the Navy Bureau of Aeronautics presented to ARPA the results of its manned satellite study, cleverly acronymized "MER I" (for "Manned Earth Reconnaissance"). This approach called for an orbital mission in a novel vehicle—a cylinder with spherical ends. After being fired into orbit by a two-stage booster system, the ends would expand laterally along two structural, telescoping beams to make a delta-wing, inflated glider with a rigid nose section. The configuration met the principal MER I requirement: the vehicle would be controllable from booster burnout to landing on water. Fabric construction obviously implied a new departure in the design of reentry vehicles. At ARPA's direction the Bureau of Aeronautics undertook a second study (MER II), this one to be done jointly on contract by Convair, manufacturer of the Atlas, and the Goodyear Aircraft Corporation. The Convair-

Goodyear study group did not make its report until December. At that time it reasserted the feasibility of the lifting pneumatic vehicle but relegated the inflation of the craft to the postentry portion of the mission.[86] By December, however, Project Mercury already was moving ahead steadily under NASA. Funds for a MER III phase (model studies) were not forthcoming from the Defense Department, and the intriguing MER concept became a little-known aspect of the prehistory of manned orbital flight.

MER, sometimes referred to as "Project MER," was by far the most ambitious of the manned space flight proposals made by the military in 1958. Its emphasis on new hardware and new techniques meant it really had little chance for approval then. Conversely, Project Adam was not ambitious enough for the time and money involved. Of the three military proposals, Man-in-Space-Soonest came closest to full program approval. But by August the Air Force's hopes for putting a man into orbit sooner than the Soviet Union, or than any other agency in this country, were fading rapidly before the growing consensus that manned space flight should be the province of the civilian space administration.

## NASA Gets the Job

After the passage of the Space Act on July 16, Killian had requested from Dryden a formal memorandum placing on record NACA's views regarding a manned satellite project. Two days later, a week and a half before Eisenhower signed the act, Dryden sent his memorandum to Killian. The NACA director sketched his organization's extensive research background in such pertinent areas as control systems for hypersonic vehicles, thermodynamics, heat-resistant structural materials, and the current X–15 project. Then, in his strongest official statement up to that time on development, operations, and managerial responsibilities, Dryden concluded, "The assignment of the direction of the manned satellite program to NASA would be consistent with the President's message to Congress and with the pertinent extracts from the National Aeronautics and Space Act of 1958. . . ." [87]

Like everyone else, including Air Force leaders, Dryden wanted to avert a potential conflict between NASA and the Air Force regarding manned space flight. On the same day that Eisenhower signed the Space Act, July 29, Dryden met with Roy Johnson and Secretary of Defense Neil H. McElroy to discuss the future management of manned space programs, but no agreement was reached. The conferees adjourned to await action from the White House.[88]

Some time between then and August 20, probably on August 18, Eisenhower made his decision. Again apparently acting on Killian's advice, he assigned to NASA specific responsibility for developing and carrying out the mission of manned space flight. This decision provided the coup de grace to the Air Force's plans for Man-in-Space-Soonest. Deputy Secretary of Defense Quarles decided the $53.8 million that had been set aside for various Air Force space projects,

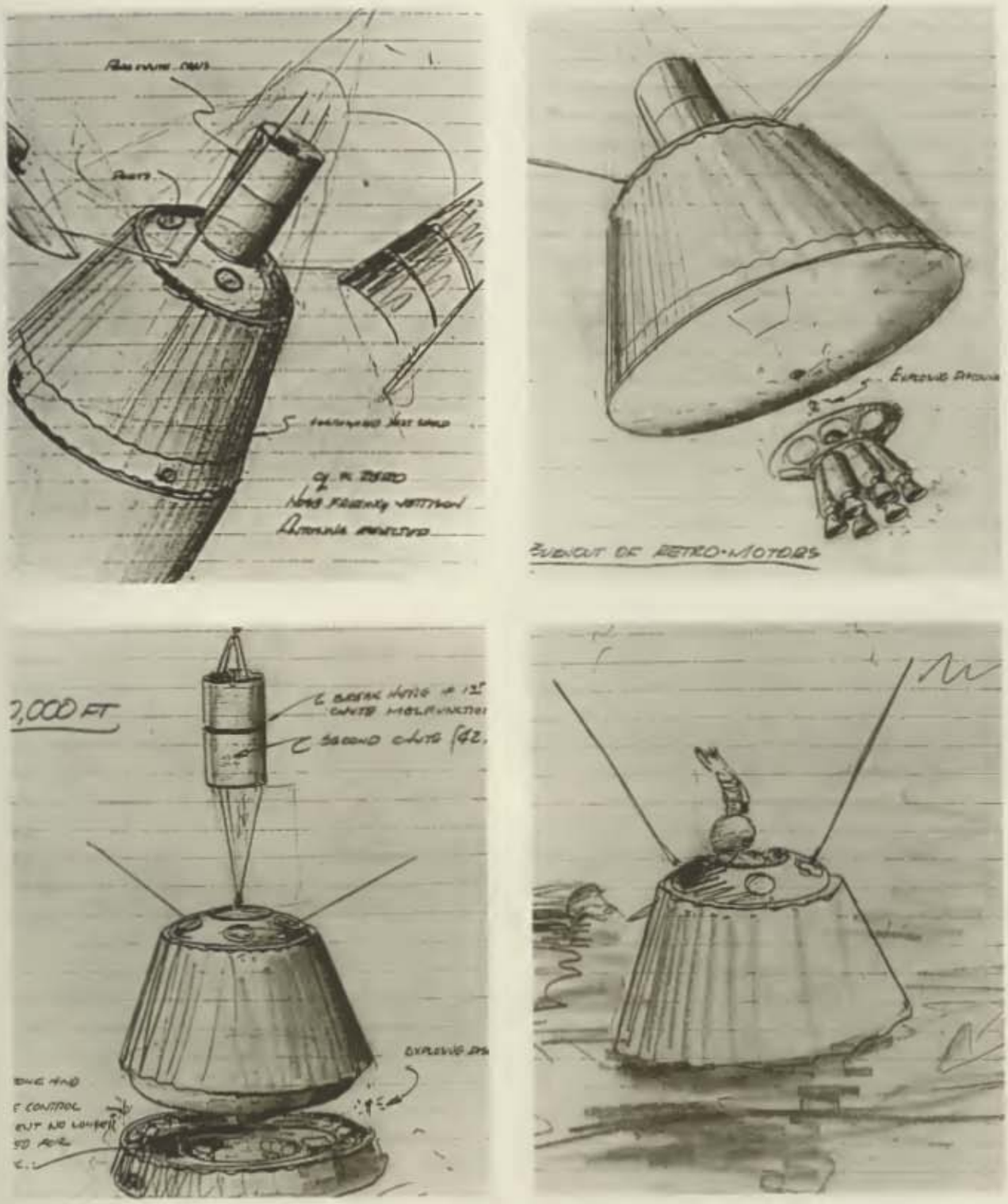
including Man-in-Space-Soonest (but not Dyna-Soar), would constitute part of the $117 million to be transferred from the Defense Department to NASA. LeMay, Air Force Vice Chief of Staff, then notified the Air Research and Development Command that he was transferring $10 million previously earmarked for the Soonest project. He added that Eisenhower's action obviously made impossible the immediate project approval Schriever had urged on July 24. A seventh and final manned satellite development plan, which the Ballistic Missile Division submitted to ARDC on September 11, significantly dropped the term "Soonest" from its descriptive title.[89]

The Air Force would proceed with its Dyna-Soar project in conjunction with NASA and later would inaugurate a "Discoverer biosatellite program" based on the 117L system. After August 1958, however, the project to rocket into orbit a man in a ballistic capsule was under undisputed civilian management, although it would draw heavily on all three services as well as industry and universities.

The National Aeronautics and Space Administration received authorization to carry out this primitive manned venture into lower space mainly because Eisenhower was wedded to a "space for peace" policy. He was joined by his closest advisers, most members of Congress, and perhaps a majority of politically conscious Americans. In 1958 there simply was no clear military justification for putting a man in orbit.[90] And while there is little evidence on this point, it may be assumed that the very ambitiousness of the Air Force planners, to whom the orbiting of a manned ballistic vehicle was only the first phase of a costly program aimed at putting a man on the Moon, discouraged the budget-conscious Eisenhower administration. Already enormous sums were being spent on ballistic missiles and other forms of advanced weapons technology.

Also helping to influence the President and his advisers, however, was the fact that NACA, around which NASA would be built, already had gone far in designing, testing, planning, and generally making itself ready for the execution of a manned satellite project. For months representatives from NACA Headquarters had conferred periodically with prospective contractors like Avco, Lockheed, and General Electric on such subjects as heatshield technology, environmental control systems, and communications requirements.[91] As early as March 1958, both before and after the Ames conference, Maxime Faget and Caldwell C. Johnson, working in PARD, together with Charles Mathews of the Langley Flight Research Division, had drawn up basic outlines for the manned ballistic satellite mission, the capsule configuration and internal equipment, heating loads and structural considerations, and weight limitations for a manned payload lifted into orbit by an Atlas. Throughout the spring and summer, Johnson, a self-made engineer attached to PARD from the Langley Engineering Services Division, continually modified his designs and specifications for the "can" to be mounted on the Atlas ICBM.[92]

By the end of the summer, experimenters operating in the 2000-foot towing tank at the Virginia laboratory already were using Langley-made scale models and




*During the spring of 1958 engineers at Langley both researched and brainstormed the problems associated with a manned spacecraft. These engineering sketches were done in May 1958 by Caldwell C. Johnson. In the upper left, the spacecraft is still attached to the booster in powered ascent; the nose fairings have just jettisoned, exposing the parachute containers and permitting the antenna to deploy. Upper right, reentry has begun and the spent retrorockets are being jettisoned. Lower left, the parachutes are deploying and the heatshield is being jettisoned. And at lower right, the spacecraft has safely landed in the water and is now communicating.*



*Two models of possible capsule configurations from early 1958. The cone shape was soon obsolete, while the rounded-end-with-cylinder configuration is clearly related to C. C. Johnson's engineering sketches. It is interesting that the couch configuration is the same in the two divergent capsule designs.*





*A water-drop test at the Langley laboratory is about to check the landing characteristics and flotation stability of the cone-shaped capsule configuration.*

dummies of the ballistic capsule in water impact trials, while other engineers were carrying out air-drop tests of a boilerplate capsule parachute system over Chesapeake Bay. And a group from the Lewis laboratory was commuting regularly to Langley to participate in design discussions on all the orbital spacecraft systems, especially on thermal protection techniques and on the attitude control, separation (posigrade), and reentry (retrograde) rockets.[93]

Meanwhile Faget's and Paul Purser's proposal made early in the year for a clustered-rocket test booster to be used in payload design research and in manned vertical flights had undergone a politic modification. After Dryden publicly drew his analogy between the Army's Project Adam and the circus lady shot from a cannon, the PARD research team leaders dropped the name "High Ride" and shelved their ideas for using the rocket to fire a man into space. In August, Faget asked William M. Bland, Jr., and Ronald Kolenkiewicz of PARD to prepare precise specifications for a vehicle to launch full-scale and full-weight capsules to a maximum altitude of 100 miles. Only a year would pass before the experimental rocket went into operation. When it did, the former "High Ride" would have acquired the new nickname "Little Joe." [94]

Only three days after Eisenhower signed the Space Act and more than two

weeks before he formally gave the manned satellite job to NASA, Dryden and several other representatives of the disappearing NACA had testified before the House space committee on their budget request for $30 million for fiscal 1959. Assistant Director Gilruth of Langley gave a hurriedly prepared presentation on plans for a manned ballistic satellite; his remarks amounted to the first open discussion of the technical aspects of what was soon to become Project Mercury. After exhibiting models of the contour couch and an outdated cone-shaped capsule, Gilruth turned to the proposed launch vehicle. Here he revealed the fears and hopes about the Atlas that would characterize NASA's efforts to orbit a man:

> The Atlas . . . has enough performance to put this in orbit and the guidance system is accurate enough, but there is the matter of reliability. You don't want to put a man in a device unless it has a very good chance of working every time.
>
> There are scheduled many Atlas firings in the next year and a half. Reliability is something that comes with practice. It is to be anticipated that this degree of reliability will occur as a result of just carrying out the national ballistic missile program.[95]

The Main Committee of NACA held its last meeting on August 21 and formally extended best wishes to NASA and Administrator Glennan, who attended the meeting.[96] In mid-September, Glennan and Roy Johnson of ARPA agreed that their two agencies should join in a "Man-in-Space program based on the 'capsule' technique." [97] They then established a joint NASA–ARPA Manned Satellite Panel to draw up specific recommendations and a basic procedural plan for the manned satellite project. Composed of Gilruth, who served as chairman, and Faget of Langley, Eggers of Ames, Williams of the Flight Station, and George M. Low and Warren J. North of Lewis, representing NASA, together with Robertson C. Youngquist and Samuel Batdorf of ARPA, the panel began holding meetings during the last week of September.[98]

On September 25, Glennan issued a proclamation declaring that "as of the close of business September 30, 1958, the National Aeronautics and Space Administration has been organized and is prepared to discharge the duties and exercise the powers conferred upon it." [99] In a message to all NACA personnel he added:

> One way of saying what will happen would be to quote from the legalistic language of the Space Act. . . . My preference is to state it in a quite different way—that what will happen . . . is a sign of metamorphosis. It is an indication of the changes that will occur as we develop our capacities to handle the bigger job that is ahead. We have one of the most challenging assignments that has ever been given to modern man.[100]

On Tuesday afternoon, September 30, more than 8000 people left work as employees of the 43-year-old NACA. The next morning almost all of them returned to their same jobs with NASA.

## *Part Two*

# DEVELOPMENT

# V

# Specifications for a Manned Satellite

(OCTOBER–DECEMBER 1958)

"All right. Let's get on with it!"

These were the informal words of leadership that launched the development of the United States' first manned space flight program. They were spoken by T. Keith Glennan, newly appointed first Administrator of the National Aeronautics and Space Administration, following a briefing by eight civil service aeronautical engineers who felt ready to become "astronautical engineers." This was exactly a year and three days after national debate and preliminary planning had been precipitated by *Sputnik I*. Glennan's words symbolized the firm resolution of the Congress, the Eisenhower administration, and the American people to accept the challenge of nature, technology, and the Soviet Union to explore the shallows of the universe.[1]

By the first anniversary of Earth's first artificial satellite, Americans generally seemed willing, if not eager, to accept the rationale of scientific experts and engineering enthusiasts that the new ocean of space could now and should now be explored by man in person. The human and the physical energies necessary for man to venture beyond Earth's atmosphere had become, for the first time in the history of this planet, available in feasible form. These energies only needed transformation by organization and development to transport man into the beyond.

If these were the articles of faith behind the first American manned satellite program, they had not been compelling enough to spark action toward space flight before the Sputniks. Public furor was inspired primarily not by the promise of extending aeronautics and missilery into astronautics, but rather by the nationalistic fervor and punctured pride caused by the obviously spectacular Soviet achievements. Faith, fervor, and even some fear were perhaps necessary if the

American democracy was to embark on a significant space program. But the people most directly concerned with mobilizing the men and the technology to accomplish manned orbital flight had first to organize themselves.

## A Manned Satellite Plan

The establishment of an organization to carry through a manned space flight program depended upon gaining the national decision to create a space agency and then upon defining the objectives of the space agency as a whole and of its highest priority programs in particular. In July 1958 legislative debate had ended in the passage of the National Aeronautics and Space Act. In August administrative power struggles had abated with President Dwight D. Eisenhower's appointments and Senate confirmation of the administrative heads of the new space agency. By September the technical and jurisdictional questions remaining to be solved for an operational manned satellite program had been removed from the open forum by their assignment to the Joint NASA–ARPA Manned Satellite Panel. When Glennan proclaimed that the demise of NACA and the birth of NASA would take effect at the close of business on September 30, 1958, there was reason to suppose that a preliminary organization of the nation's space program was well in hand. But in Washington there was no clear commitment to the precise size or priority of the manned program within NASA, because NASA itself was as yet only a congeries of transferred people, facilities, and projects.[2]

Earlier attempts to coordinate interservice and interagency plans and procedures for putting a man in space had been ineffectual. During the middle of September, Glennan and Roy W. Johnson, Director of Advanced Research Projects Agency (ARPA), had come to agree on the bare outline of a joint program for a manned orbital vehicle based on the ballistic capsule idea. A month earlier, Hugh L. Dryden, the veteran Director of the NACA, and Robert R. Gilruth, Assistant Director of Langley Aeronautical Research Laboratory, had informed Congressional committees of their plans for a manned capsule and had requested $30 million to proceed with the work. But only when the Joint Manned Satellite Panel was established by executive agreement between NASA and ARPA in mid-September 1958 did plans and proposals begin to jell into a positive course of action.[3]

Of the eight members of this steering committee, only two were from ARPA. Six had come from NACA and were the principal policy makers who laid down the guidelines and objectives for the first manned space flight program. This group began to meet almost continuously in late September in an effort to establish preliminary plans and schedules for the manned satellite project. Thousands of scientists and engineers over past years made possible their outline report, entitled "Objectives and Basic Plan for the Manned Satellite Project." But technical liaison between military and civilian groups on the immediate working levels provided the specific data for the outline drawn up by this panel: [4]

SPECIFICATIONS FOR A MANNED SATELLITE

I. OBJECTIVES

The objectives of the project are to achieve at the earliest practicable date orbital flight and successful recovery of a manned satellite, and to investigate the capabilities of man in this environment.

II. MISSION

To accomplish these objectives, the most reliable available boost system will be used. A nearly circular orbit will be established at an altitude sufficiently high to permit a 24-hour satellite lifetime; however, the number of orbital cycles is arbitrary. Descent from orbit will be initiated by the application of retro-thrust. Parachutes will be deployed after the vehicle has been slowed down by aerodynamic drag, and recovery on land or water will be possible.

III. CONFIGURATION

A. *Vehicle*

The vehicle will be a ballistic capsule with high aerodynamic drag. It should be statically stable over the mach number range corresponding to flight within the atmosphere. Structurally, the capsule will be designed to withstand any combination of acceleration, heat loads, and aerodynamic forces that might occur during boost and reentry of successful or aborted missions.

The document outlined generally the life support, attitude control, retrograde, recovery, and emergency systems and described the guidance and tracking, instrumentation, communications, ground support, and test program requirements.

In only two and one-half pages of typescript, the "Objectives and Basic Plan" for the manned satellite were laid out for the concurrence of the Director of ARPA and the Administrator of NASA during the first week of October 1958. Verbal elucidations of accompanying charts, tables, and diagrams, plus scale models brought along from Langley Field, successfully sold this approach for putting man into orbit. Although the Air Force, Army, and Navy, as well as numerous aviation industry research teams, also had plans that might have worked equally well, the Nation could afford only one such program. The simplest, quickest, least risky, and most promising plan seemed to be this one.[5]

The fact that the Joint Manned Satellite Panel was "loaded" six to two in favor of NASA reflected the White House decision that ARPA would assist NASA rather than comanage the project. The plans of the panel gave the appearance of unanimity among aeronautical engineers on how to accomplish manned orbital flight. Keith Glennan and Roy Johnson were impressed by this consensus but they refrained from making public their commitments for several more months. The tacit agreement among the panel members that no basic technical or scientific problems remained to be solved before moving into development and flight test would be tested by industrial response to the basic plan. If previous research had been sufficiently thorough to allow NASA to begin immediately applying engineering knowledge for the achievement of orbital flight, then the panel's judgment of

the state of the art should be confirmed by the aircraft companies. Only Alfred J. Eggers wished to be placed on record as favoring concurrent development of a lifting reentry vehicle.[6]

The panel recommended three types of flight testing programs. First, development tests should verify the components of the manned satellite vehicle "to the point where they consistently and reliably perform satisfactorily, and provide design criteria by measuring loads, heating, and aerodynamic stability derivatives during critical portions of the flight." Second, qualification flight tests should determine suitability of the complete vehicle to perform its specified missions. Third, training and pilot performance flight tests should validate man's "potential for the specified missions."

> In this program, all three types of tests will be made with full-scale articles. These tests will be initiated at low velocities, altitudes and loads. They will progress with a buildup in severity of these conditions until the maximum mission is reached. In general, development tests will be completed, followed by qualification tests, and pilot performance and training tests. However, there will be some overlap as the severity of conditions are built up in the flight test program. The number and type of pilot performance and training flights will be determined as the program develops.[7]

Although the conceptual design and the operating philosophy for the manned satellite program were remarkably firm at the time of authorization, specific technical difficulties in development could not be pinpointed in advance. The people who would have to solve them were only then being identified and appointed to their individual jobs. At NACA Headquarters in Washington, Hugh Dryden had presided during the summer over the metamorphosis of NACA into NASA. An established scientist and a proven technical executive, Dryden had been a logical choice if not for the Administrator, then for Deputy Administrator, the second highest position within the space agency. He must decide how many and who should move to Washington to manage the administrative side and to oversee the engineering work. What proportion of effort and funds should NASA spend on developing manned, as opposed to unmanned, spacecraft and rockets? On whom should the immediate responsibility for technical direction of the manned satellite program be put? Where should the locus for ground control of manned space flight operations be placed?

## The People in Charge

Glennan and Dryden decided many questions of appointment quite naturally by allowing informal working arrangements to become formal. Glennan's fellow Clevelander, Abe Silverstein, Associate Director of NACA's Lewis Flight Propulsion Laboratory, was appointed Director of Space Flight Development. Silverstein had been the technical director of research at Lewis since 1949 and had worked closely with Dryden since March and with Glennan since August in plan-

ning the early organization of NASA.[8] As reflected by his title, manned programs per se were supposed to occupy only about one-third of Silverstein's time. He brought with him from Cleveland three other scientist-administrators of demonstrated talents to handle most of his staff work concerning the manned satellite program, which then was a minor portion of Silverstein's responsibility compared with his concerns over propulsion development. Newell D. Sanders became Silverstein's Assistant Director for Advanced Technology. But the primary relations between Washington and the field activities for manned space flight development were to be handled by George M. Low, who eventually became chief of an Office of Manned Space Flight, and Warren J. North, a former NACA test pilot who at first headed an Office of Manned Satellites, then of Space Flight Programs. Dryden and Glennan depended heavily upon Silverstein and his aides for the technical review and supervision of the division of labor among the various NASA field centers. But the locus of manned space flight preparations remained with the small group of Langley and Lewis personnel under Gilruth, the group that had zealously researched, planned, and designed what was to become Project Mercury.

Dryden desired to conserve the character of the three primary NACA centers as national laboratories specializing as necessary in applied and advanced research for aeronautics and astronautics. Glennan agreed to assign the large new development and operational programs to distinct, or at least reorganized, groups of people. The directors of the Langley, Ames, and Lewis Research Centers should continue their aeronautical and missile work with a minimum of disturbance while expanding the proportion of their research devoted to space. NASA Headquarters personnel, temporarily located in the Dolley Madison House, across Lafayette Square from the White House, should be able to coordinate agency-wide activities without too much interference in the high degree of local autonomy at the research laboratories near airfields in Virginia, California, and Ohio.

With the birth of NASA all the former NACA laboratories had their names changed. Langley Memorial Aeronautical Laboratory, from 1920 until 1940 the first and only research lab for NACA, became on October 1, 1958, the Langley Research Center. Located on the Virginia peninsula, across Hampton Roads from Norfolk, the Langley laboratories flanked one side of old Langley Field, one of the pioneer U.S. military airfields; for 10 years now the Air Force had called it the Langley Air Force Base. NASA's 700 acres there contained buildings and hangars more permanent and other structures more unusual than were normally found at military airfields. On opposite edges of the runways, about 3000 civilians in 1958 worked at facilities worth more than $150 million. About 700 of these people were professional engineers and self-made scientists whose major tools were 30 different wind tunnels. Also they had experimental models, operating aircraft, shops, and laboratories for chemistry, physics, electronics, and hydrodynamics.[9]

As a national aeronautical laboratory Langley supported little if any "pure"

or "basic" science, in the sense of independent individual investigations in pursuit of knowledge as opposed to utility. But it had long provided a world-renowned institutional setting for "applied science." Both research and development were carried on there without prejudice.[10]

Now that the "sky" was to be redefined in terms of "aerospace," man's mastery of dimensions at least five times higher than he had ever flown required radically new social as well as technological inventions. Silverstein was asked by Dryden to help Gilruth create an entirely new management organization, composed primarily of Langley personnel, without disrupting other work in progress. The Director of Langley Research Center, Henry J. E. Reid, was on the verge of retirement, and responsibility for administering Langley had devolved to Floyd L. Thompson. Neither Reid nor Thompson was close enough to the manned satellite working level, where events were moving so rapidly, to assume charge of the special organization taking shape there.

The project director of the manned satellite program should therefore be the man who had already directed it through its gestation period—Robert R. Gilruth. As Assistant Director of Langley and the former chief of the Pilotless Aircraft Research Division (PARD), he had long nurtured Maxime A. Faget and his associates, the conceptual designers of the NACA manned satellite. After the consolidation of professional consensus at Langley behind the Faget plan in March 1958, Dryden and his Washington associates Ira H. Abbott and John W. Crowley, Jr., had given Gilruth authority to get underway.[11]

Gilruth had come to Langley after earning his master's degree in aeronautical engineering at the University of Minnesota under Professor Jean Piccard in 1936. He had been a leader in research during the development of transonic and supersonic aircraft, becoming the man in charge of structures, dynamic loads, and pilotless aircraft studies at Langely in 1952. During the decade of guided missile development, Gilruth had served on some six scientific advisory committees for the military services and for NACA. His eminence was widely recognized both as a scientist-engineer and as a research administrator. Furthermore, he was eager to continue his leadership of the vigorous group of younger engineers working with Faget.[12]

As soon as Gilruth and Faget returned with Glennan's verbal approval "to implement the manned satellite project," Thompson, acting director of Langley, began making arrangements to establish in separate facilities at the Unitary Wind Tunnel Building the self-appointed group already working on space flight. Charles J. Donlan, Technical Assistant to the Director of Langley, was asked to serve as Assistant Project Manager. Under Gilruth and Donlan, 33 Langley personnel, 25 of these engineers (14 of them from PARD), were officially transferred on November 5, 1958, to form the nucleus of a separate organization to be called the Space Task Group.[13]

Although the new Task Group was responsible directly to Washington, its initial composition and actions were left largely to local initiative. The Langley

group had anticipated by two months the official actions and had discussed organization of a "Manned Ballistic Satellite Task Group." Called by some of its secretaries the "Space Task Force," it had acquired 10 to 15 men from Lewis Research Center when Silverstein in July had directed them to commute to Langley to aid in working out detailed designs for structure, thermal protection, and instrumentation in the program. This informal Langley-Lewis working arrangement gradually integrated and expanded as the Space Task Group took shape through the following year.[14]

Gilruth's authorization gave him two hats: one as project manager of the Space Task Group, and the other—announced May 1, 1959—as assistant director of a new NASA "space projects center" to be located near Greenbelt, Maryland, about 15 miles northeast of the Nation's capital. In Washington, Dryden and Silverstein were making plans for this space development facility to accommodate the NASA inheritance of Project Vanguard and about 150 of its personnel, transferred from the Naval Research Laboratory. Such a facility might easily double as an operations control center. At this time the scientific and operational aspects of manned satellites appeared to complement the tracking network and instrumentation for the Vanguard satellites. So as soon as the building could be constructed on an agricultural experimental farm at Beltsville, Maryland, the Space Task Group would move there. In the interim Langley would continue to furnish lodging and logistic support while a space flight operations center was being built. All this was to change about two years later when it became apparent that the scope, size, and support for manned space endeavors called for an entirely separate center.[15]

Everyone connected with the Space Task Group in the first several months of its existence was too busy preparing and mailing specifications, briefing prospective contractors, and evaluating contractor proposals to take much interest in organization charts. A kind of executive committee, forming around Gilruth and Donlan during November and December, gradually organized itself along functional lines. Gilruth and Donlan, Faget and Paul E. Purser, Charles W. Mathews, and Charles H. Zimmerman formed the core of this first executive council. Other senior NACA engineers on the original STG personnel list, men like Aleck C. Bond, Christopher C. Kraft, Jr., Howard C. Kyle, George F. MacDougall, Jr., and Harry H. Ricker, Jr., also played important roles in the initial formulation of the technological plan of attack.

Of the 35 members of the original group from Langley, only eight provided administrative or clerical services. Thus, with the 10 additional people from the Lewis laboratory, Gilruth and Donlan had 35 scientist-engineers to assign to specific technical problems. Those 14 who came directly from PARD continued working on implementing their designs, as they had been doing for almost a year. Five men came from the Flight Research Division of Langley, two came from the Instrument Research Division, two from the Stability Research Division, and one each from the Dynamic Loads and Full-Scale Tunnel Research Divisions.

Some of these, men like William M. Bland, Jr., John P. Mayer, Robert G. Chilton, Jerome B. Hammack, Jack C. Heberlig, William T. Lauten, Jr., and Alan B. Kehlet, had made substantial professional investments in the space flight program at a time when this was still some risk to their careers. Being a Buck Rogers buff was not yet quite respectable.[16]

From Glennan's approval of the project until the formal establishment of the Space Task Group on November 5, and indeed for some months later, it was by no means certain how much support and what priority the manned satellite program might receive. Some NACA careerists were hesitant to join an operation that might easily prove abortive. So far Gilruth had no specified billets to fill nor any public, formal mandate from Headquarters. He and Silverstein worked together very closely through the shuttle service of George Low on Silverstein's staff, who divided his time between Washington and STG. The hectic early days, cluttered and confused, made the future of the Task Group appear less than certain. Although NASA Headquarters had received from ARPA and allocated to Langley the necessary funds to get started, NASA seemed to prefer the science programs it had inherited along with instrumented satellites. The Space Task Group wanted full and explicit support of the development engineering necessary for a manned satellite. But the members did not let lack of documented clarity from the policy level dampen their enthusiasm or activity. Throughout October, trips and conferences by key personnel verified at the working level and in the field what could and could not be done to implement policy planning in Washington. To many of the younger engineers under Gilruth, NASA's initial organizational confusion offered opportunity for initiative at the local level to accomplish more than directives from Headquarters in getting an American into orbit.[17]

In order to avoid the danger of converting the Langley Research Center into Langley "Research and Development" Center, Dryden insisted that the Space Task group should be separated from the mother institution and attached to the Beltsville Center. Some Langley engineers welcomed the opportunity to participate in a full-fledged development program; others, more research-oriented, abhorred the idea. In managing the Space Task Group, Gilruth had to reconcile these attitudes, to recruit talent and screen zeal, and to create an organization capable of developing into hardware what had been conceived in research.

## "Aerospace" Technology

One of the scientific questions of the International Geophysical Year that had to be answered before the orbital mechanics of a manned satellite could be specified in detail was: where precisely does Earth's atmosphere end? By late 1958 the aeromedical fraternity, following Hubertus Strughold's lead, had accepted the conceptual outlines of "space-equivalent altitudes," with refined definitions of the "aeropause," as a general biological guide to answer a slightly different question:

where does space begin? But upper-atmospheric studies, based on the actual behavior of the six or eight known artificial satellites plus the data gained from a few rocket probes and about 100 comparable sounding rockets and balloons, were neither definite enough nor codified well enough to plan the precise height at which man should first orbit Earth.[18]

The NASA/ARPA mission specification of a circular orbit to be achieved by "the most reliable available boost system . . . at an altitude sufficiently high to permit a 24-hour satellite lifetime" (before the natural decay, or degradation, of the original orbit because of slight but effective upper-atmospheric friction) had carefully avoided a commitment to either a booster or an orbital altitude. The Space Task Group proceeded on the assumption that both apogee and perigee of the manned ballistic satellite should be within the rough limits of 100±25 miles high. The Task Group chose 100 statute miles (87 nautical miles) as the nominal average altitude to ensure a full-Earth-day lifetime for the one-ton manned moonlet.

The outer limits of Earth's atmosphere, where it blends in equilibrium with the solar atmosphere or plasma, seemed around 2000 miles, and the "edge" of the outer ionospheric shell was thought to be perhaps 4000 miles above sea level, but these were irrelevant parameters for orbit selections. ICBM performance data at that time made it certain that the "most reliable available boost system" could not boost a 2200-pound ballistic capsule even to the 400-or-so-mile "floor" of the Van Allen belt.[19]

The Atlas ICBM was still "the most reliable available boost system"; there was as yet no viable alternative booster. All preliminary hardware planning had been based on the assumption that the Atlas would prove its power and prowess very soon. The NACA nucleus of NASA was composed for the most part of aeronautical engineers, airplane men not yet expert with missiles and rockets. Few of them at first fully realized how different were the flight regimes and requirements for the technology of flight without wings.

Since World War II winged guided missiles or pilotless drone airplanes had given way to rocket-propelled ballistic projectiles; by 1958 the industrial base and engineering competence for missilery had matured separately from and tangentially to the aviation industry.[20] If the manned satellite program were to become the first step for sustained manned space flight, a new synthesis between science and engineering and a new integration between the aircraft and missile industries would be necessary. "Space science" and "aerospace technology," terms already made popular by the Air Force, were now in the public domain, but their meanings were vague and ambiguous so long as they held so little operational content. Silverstein, Crowley, and Albert F. Siepert, the men who became the first executive directors of the top three "line offices" of NASA Headquarters, indubitably had their debates on programming operations for NASA and the Nation. But on the need for new syntheses and reintegrations of established disciplines and industries there could be no debate. NASA's legal mandate to coordinate and to contract

for cooperative development "of the usefulness, performance, speed, safety, and efficiency of acronautical and space vehicles" was second only to its first objective in the Space Act, expanding "human knowledge of phenomena in the atmosphere and space." [21]

The complex prehistory of NASA and the manned satellite program began to impinge on NASA policy. It affected project planners as soon as they set forth their intention to put a man into orbit. Industrial and military investments in feasibility studies to this same goal had been heavy. The Space Task Group decided in mid-October to withdraw from all contacts with industrial contractors while finishing its preliminary specifications for the manned satellite capsule. STG thus avoided any accusations of favoritism, but lost about two months in time before it was able to acquire the latest classified and proprietary studies and designs by other organizations.

Three most pertinent examples of industrial research going on concurrently with government research and leading up to seminal proposals for manned satellite specifications were those studies being conducted by the Convair/Astronautics Division (CV/A) of the General Dynamics Corporation in conjunction with the Avco Manufacturing Corporation, studies by the General Electric Company in conjunction with North American Aviation, Inc., and those by McDonnell Aircraft Corporation. The CV/A-Avco proposal to the Air Force in April 1958 for a spherical drag-braked manned satellite was followed by more reports by CV/A in June and November, and these proved that the builders of the Atlas were exploring every avenue for civilian uses of their booster rocket. Convair men like Karel J. Bossart, Mortimer Rosenbaum, Charles S. Ames, Frank J. Dore, Hans R. Friedrich, Byron G. MacNabb, F. A. Ford, Krafft A. Ehricke, and H. B. Steele had a continuing interest in seeing their fledgling weapons carrier converted into a launch vehicle for manned space flight, either with or without an upper stage.

At NASA Headquarters, Abe Silverstein decided early in November to formalize his earlier approval of Faget's plan for the "bare Atlas." On that basis a formal bidders' briefing for the capsule contract was planned for November 7. Only after mid-December, when all the proposals were in, did STG learn how great had been other industrial investments in research for a manned ballistic satellite.[22]

Although the Atlas airframe, design, and systems integration had all grown directly out of Convair engineering development, the liquid-fueled rocket engines for the Atlas, as well as for the Redstone, Jupiter, and Thor missiles, were all products of the Rocketdyne Division of North American Aviation, Inc. Hence North American, when teamed with another corporate giant, General Electric, appeared also to be a prime contender for the manned satellite contract. The Space Task Group was only dimly aware at this time of the specifications that had emerged from North American and General Electric as proposals for the Air Force's "Man-in-Space-Soonest" studies, but it did know at least that its own ballistic capsule plan was at variance with the "high lift over drag" thinking at North American.[23]

## SPECIFICATIONS FOR A MANNED SATELLITE

Back in May 1957, five months before *Sputnik I,* James S. McDonnell, Jr., the founder and president of a growing aircraft corporation bearing his name, gave an address at an engineering school commencement ceremony. He predicted a speculative timetable for astronautics that placed the achievement of the first manned Earth satellite, weighing four tons and costing one billion dollars, between the years 1990 and 2005 A.D. One year later, in a similar address, McDonnell sagaciously abandoned his timetable and said:

> I think it is fortunate that the Soviets have boldly challenged us in [space science and exploration] . . . . Their space challenge is a fair challenge. We should accept this challenge and help to turn it primarily into peaceful channels.
>
> * * *
>
> So, fellow pilgrims, welcome to the wondrous age of astronautics. May serendipity be yours in the years to come as man stands on the earth as a footstool and reaches out to the moon, the planets, and the stars.[24]

Off and on since *Sputnik II,* McDonnell Aircraft Corporation's Advanced Planning Group had assigned first 20, then 40, and, from April through June 1958, some 70 men to work on preliminary designs for a manned satellite capsule. Led by Raymond A. Pepping, Lawrence M. Weeks, John F. Yardley, and Albert Utsch, these men had completed a thoroughgoing prospectus 427 pages in length by mid-October 1958. People at Langley had been aware of this work in some detail, but when NACA and PARD became part of NASA, a curtain of discretion fell between them and STG. The McDonnell proposal was repolished during November before it took its turn and its chances with all the rest of the bidders.[25]

While interested aerospace companies were endeavoring to fulfill the Government's plans and specifications for a manned satellite, a number of men in the institutional setting at Langley were busily engaged in final preparations for the bidders' conference. Craftsmen like Z. B. Truitt and Scott Curran, in the Langley shops, fabricated new models of both the couch and the capsule for demonstration purposes. Engineering designers like Caldwell C. Johnson and Russell E. Clickner, Jr., reworked multiple sets of mechanical drawings until Faget and the Task Group were satisfied that they had the architectonic engineering briefing materials ready for their prospective spacecraft manufacturing contractors. Gilruth, Donlan, Mathews, and Zimmerman meanwhile approved the block diagrams of systems as they evolved. They looked over their requirements for outside support in future launching operations, flight operations, trouble-shooting research, and crew selection and training. With everything going on at once among half a hundred men at most, there was no time now in STG for second thoughts or doubts about whether the "Faget concept" would work.[26]

Questions of policy and personnel at the time of the organization of NASA and during the birth of this nation's manned space flight program were affected significantly by a conflict then existing between the experts on men and the experts on missiles. In the eyes of the Space Task Group, the medical fraternity, particularly some Air Force physicians, was exceedingly cautious, whereas the Space

Task Group seemed overly confident to some Air Force medical men and some of their pilots. During the deliberations of the joint NASA–ARPA Manned Satellite Panel, the contrast between the technical aspects of the Air Force's "Man-in-Space-Soonest" proposal and the Faget plan sponsored by the Langley-PARD group had been resolved in favor of the latter. Air Force planners of the Air Research and Development Command early had accepted a basic ground rule specifying 12 g as the design limit for capsule reentry loads. They had opposed the so-called "bare Atlas" approach, which would carry the risk of imposing accelerations up to 20 g in case of a mid-launch abort. As a last resort they too had turned to the standard Atlas as the most feasible launch vehicle, even though, Faget believed, Air Force aeromedical experts had not accepted the significance of the physiological demonstrations by Carter C. Collins and R. Flanagan Gray on the Navy's centrifuge at Johnsville in July that man could sustain 20 g without lasting harmful effects. In calculating the risks in manned space flight, the group at Langley saw this event as having paramount importance.[27]

To ensure that NASA would have intelligent liaison and some expertise of its own in dealing with military aeromedical organizations, one of the early official actions of the NASA Administrator was the appointment on November 21 of a Special Committee on Life Sciences, headed by W. Randolph Lovelace II. This committee, composed of members from the Air Force, Army, Navy, Atomic Energy Commission, Department of Health, Education, and Welfare, and private life, should provide "objective" advice on the role of the human pilot and all considerations involving him. However, NASA and particularly STG would soon discover certain difficulties with this, as with other, review committees "having a certain amount of authority . . . yet no real responsibility" for seeing that the program worked properly.[28]

On a similar but lower plane, Gilruth asked for and received from the military services three professional consultants for an aeromedical staff. Lieutenant Colonel Stanley C. White from the Air Force and Captain William S. Augerson from the Army were physicians with considerable experience in aerospace medicine, and Lieutenant Robert B. Voas from the Navy held a Ph. D. in psychology. Thus both NASA and STG ensured the autonomy of their medical advice while at the same time they tapped, through White, the biomedical knowledge gained by the Air Force in its "Man-in-Space-Soonest" studies and, through Augerson, that gained by the Army and Navy through joint biosatellite planning.[29]

### Calling for a Capsule Contractor

The Space Task Group was ready by October 20, 1958, to initiate the formal quest for the best builder of a spacecraft. Silverstein, Gilruth, Donlan, Faget, Mathews, and Zimmerman had decided what they wanted; now the top-priority need was to decide which contractor would be most competent to con-

struct, at maximum reliability and speed and with minimum cost and risk, the first manned spacecraft.

Preliminary specifications for capsule and subsystems were mailed by the Langley procurement office to more than 40 prospective firms on October 23, 1958. Thirty-eight of these companies responded by sending representatives to the bidders' conference at Langley Field on November 7. The briefing was conducted by Faget, Alan Kehlet, Aleck Bond, Andre Meyer, Jack Heberlig, and several others from STG and Langley. The verbal exchange of ideas at this meeting was preliminary to corporate expressions of interest expected by STG before mid-November. After that the Task Group would mail out formal specifications as the basis for bid proposals to be submitted before December 11, 1958. After his part of the briefing, Faget was asked by one of the representatives whether the retrorockets described could also be used for escape. Faget said no and explained why not. He then made it clear that any alternative capsule configurations would be considered "provided that you incorporate the retrorocket principle, the non-lifting principle, and the non-ablating heat sink principle." [30]

Nineteen of the companies present expressed interest in the competition; they were mailed copies of STG's 50-page "Specifications for Manned Space Capsule" on November 14, 1958. This document, officially numbered "S–6," formally described STG's expectations of the missions, configurations, stabilization and control, structural design, onboard equipment, instrumentation, and testing for manned orbital flight, but significantly it did not deal in detail with reliability, costs, or schedules for flight testing.[31]

By December 11, the deadline for bid proposals, the list of original competitors had narrowed to 11; there was a late starter in Winzen Research, Inc., whose proposal was incomplete. All but three of these manufacturers had been engaged for at least a year with feasibility studies related to the Air Force plans for a manned satellite. Of the 11, the eight corporations with deepest investments were Avco, Convair/Astronautics, Lockheed, Martin, McDonnell, North American, Northrop, and Republic. The three other bidders were the Douglas, Grumman, and Chance-Vought aircraft companies. Significantly perhaps, certain other major missile and aircraft companies, like Bell, Boeing, and United Aircraft, were not represented. Bell was preoccupied with the Dyna-Soar studies; Boeing also was working on Dyna-Soar and had obtained the prime contract for the Minuteman missile system; and United Aircraft sent its regrets to Reid that it was otherwise deeply committed.[32] Other military research and development contracts, such as those for the XB–70 "Valkyrie" and XF–108 were also competing for the attention of the aerospace industry.

The Space Task Group and NASA Headquarters meanwhile had worked out the procedures for technical assessment of these manufacturers' proposals and for contractual evaluations and negotiations. At Langley, a Technical Assessment Committee headed by Donlan was to appoint 11 component assessment teams to rate the contending companies in each of 11 technical areas. The classification

system set up by the Space Task Group to evaluate these competitors for the spacecraft contract illustrated the major areas of concern.

Between four and six research engineers sat on each of the following 11 components assessment teams: systems integration; load, structure, and heatshield; escape system; retrograde and landing system; attitude control systems; environmental systems; pilot support and restraint system; pilot displays and navigational aids; communications systems; instrumentation sensors, recorders, and telemeters; and power supplies. Each area was rated on a five-point scale ranging from excellent to unsatisfactory; the scores from these ratings were averaged to provide an overall technical order of preference.

All this had to be done over the Christmas holidays and while the Task Group was moving from the Unitary Wind Tunnel building on the west side of Langley Air Force Base to new quarters in an old NACA building on the east side. Early in January at NASA Headquarters a similar assessment team would gather to evaluate the competitors on their competence in management and cost accountability. MacDougall was to be the only Task Group representative on the "business evaluation" committee. Finally, a Source Selection Board, chaired by Silverstein at NASA Headquarters and including Zimmerman from STG, would review the grading, approve it, and make its final recommendation for the choice of the spacecraft contractor.[33]

Although virtually everyone in the Task Group participated in the process of selecting the capsule builder, there were other equally pressing tasks to be accomplished as soon as possible. Procurement of booster rockets, the detailed design and development of a smaller, cheaper test booster, and the problem of finding the best volunteers to man the finished product—these were seen as the major problems requiring a head start in the fall of 1958.

## Shopping for the Boosters

Booster procurement was perhaps the most critical, if not the highest priority task to be initiated. Once the Hobson's choice had been made to gear a manned satellite project to the unproven design capabilities of the Atlas ICBM, the corollary decision to use the most reliable of the older generation of ballistic missiles for testing purposes followed ineluctably. While the intercontinental-range Atlas was still being flight-tested, the medium-range Redstone was the only trustworthy booster rocket in the American arsenal. For suborbital tests, the intermediate-range Jupiter and Thor bosters were possible launch vehicles, but as yet they were neither capable of achieving orbital velocities nor operationally reliable.[34]

Even while the Joint Manned Satellite Panel was briefing the administrators of ARPA and NASA during the first week in October, Purser, Faget, North, and Samuel Batdorf flew to Huntsville for a business conference with the Army Ballistic Missile Agency regarding procurement of launch vehicles. Wernher von Braun's people assured their NASA visitors that Redstone missiles could be made available

on 12 to 14 months' notice and that the Army's Jupiters were far superior to the Thors of the Air Force. Although the Space Task Group had already consulted the Air Force Ballistic Missile Division, at Inglewood, California, and was considering the Thor for intermediate launchings, a careful reconsideration of the adaptability of each weapon system as a launch vehicle for a manned capsule was now evidently required. The so-called "old reliable" Redstones might have been ordered right away. But the question of the need for intermediate qualification and training flights along ballistic trajectories was not yet settled.[35] So more visitations to the Air Force and Army missile centers were arranged.

STG's wager on the Atlas was formalized by an order to the Air Force, placed on December 8, 1958, for first one, then nine of these Convair-made liquid-fueled rockets. The Air Force Ballistic Missile Division, heretofore the only customer for the Atlas, agreed to supply one Atlas, a C-model, within six months and the rest, all standard D-models, as needed over a period of several years. Faget was pleasantly surprised to know an Atlas-C could be furnished so soon. Having placed its first and primary order with the Air Force, the Space Task Group went on to decide a month later to buy eight Redstones and two Jupiter boosters from the Army Ordnance Missile Command. The decision to procure both medium- and intermediate-range boosters from the same source hinged largely on the fact that the Jupiter was basically an advanced Redstone. Both were Army-managed and developed and Chrysler-built. To adopt the Thor would have required another orientation and familiarization program for NASA engineers.[36]

Informed that the Atlas prime movers would cost approximately $2.5 million each and that even the Redstone would cost about $1 million per launching, the managers of the manned satellite project recognized from the start that the numerous early test flights would have to be accomplished by a far less expensive booster system. In fact, as early as January 1958 Faget and Purser had worked out in considerable detail on paper how to cluster four of the solid-fuel Sergeant rockets, in standard use by PARD at Wallops Island, to boost a manned nose cone above the stratosphere. Faget's short-lived "High Ride" proposal had suffered from comparisons with "Project Adam" at that time, but in August 1958 William Bland and Ronald Kolenkiewicz had returned to their preliminary designs for a cheap cluster of solid rockets to boost full-scale and full-weight model capsules above the atmosphere. As drop tests of boilerplate capsules provided new aerodynamic data on the dynamic stability of the configuration in free-fall, the need for comparable data quickly on the powered phase became apparent. So in October a team of Bland, Kolenkiewicz, Caldwell Johnson, Clarence T. Brown, and F. E. Mershon prepared new engineering layouts and estimates for the mechanical design of the booster structure and a suitable launcher.[37]

As the blueprints for this cluster of four rockets began to emerge from their drawing boards, the designers' nickname for their project gradually was adopted.

Since their first cross-section drawings showed four holes up, they called the project "Little Joe," from the crap-game throw of a double deuce on the dice. Although four smaller circles were added later to represent the addition of Recruit rocket motors, the original name stuck. The appearance on engineering drawings of the four large stabilizing fins protruding from its airframe also helped to perpetuate the name Little Joe had acquired.

The primary purpose of this relatively small and simple booster system was to save money—by allowing numerous test flights to qualify various solutions to the myriad problems associated with the development of manned space flight, especially the problem of escaping from an explosion midway through takeoff. Capsule aerodynamics under actual reentry conditions was another primary concern. To gain this kind of experience as soon as possible, its designers had to keep the clustered booster simple in concept; it should use solid fuel and existing proven equipment whenever possible, and should be free of any electronic guidance and control systems.[38]

The designers made the Little Joe booster assembly to approximate the same performance that the Army's Redstone booster would have with the capsule payload. But in addition to being flexible enough to perform a variety of missions, Little Joe could be made for about one-fifth the basic cost of the Redstone, would have much lower operating costs, and could be developed and delivered with much less time and effort. And, unlike the larger launch vehicles, Little Joe could be shot from the existing facilities at Wallops Island. It still might even be used to carry a man some day.

Twelve companies responded during November to the invitations for bids to construct the airframe of Little Joe. The technical evaluation of these proposals was carried on in much the same manner as for the spacecraft, except that Langley Research Center itself carried the bulk of the administrative load. H. H. Maxwell chaired the evaluation board, assisted by Roland D. English, Johnson, Mershon, and Bland of the Space Task Group. English later became Langley's Little Joe Project Engineer, Bland the STG Project Engineer, and Mershon the NASA representative at the airframe factory. The Missile Division of North American Aviation won the contract on December 29, 1958, and began work immediately at Downey, California, on its order for seven booster airframes and one mobile launcher.[39]

The primary mission objectives for Little Joe as seen in late 1958 (in addition to studying the capsule dynamics at progressively higher altitudes) were to test the capsule escape system at maximum dynamic pressure, to qualify the parachute system, and to verify search and retrieval methods. But since each group of specialists at work on the project sought to acquire firm empirical data as soon as possible, more exact priorities had to be established. The first flights were to secure measurements of inflight and impact forces on the capsule; later flights were to measure critical parameters at the progressively higher altitudes

of 20,000, 250,000, and 500,000 feet. The minimum aims of each Little Joe shot could be supplemented from time to time with studies of noise levels, heat and pressure loads, heatshield separation, and the behavior of animal riders, so long as the measurements could be accomplished with minimum telemetry. Since all the capsules boosted by the Little Joe rockets were expected to be recovered, onboard recording techniques would also contribute to the simplicity of the system.[40]

Unique as the only booster system designed specifically and solely for manned capsule qualifications, Little Joe was also one of the pioneer operational launch vehicles using the rocket cluster principle. Since the four modified Sergeants (called either Castor or Pollux rockets, depending upon modification) and four supplemental Recruit rockets were arranged to fire in various sequences, the takeoff thrust varied greatly, but maximum design thrust was almost 230,000 pounds. Theoretically enough to lift a spacecraft of about 4000 pounds on a ballistic path over 100 miles high, the push of these clustered main engines should simulate the takeoff profile in the environment that the manned Atlas would experience. Furthermore, the additional powerful explosive pull of the tractor-rocket escape system could be demonstrated under the most severe takeoff conditions imaginable. The engineers who mothered Little Joe to maturity knew it was not much to look at, but they fondly hoped that their ungainly bastard would prove the legitimacy of most of the ballistic capsule design concepts, thereby earning its own honor.

Although Little Joe was designed to match the altitude-reaching capability of the Redstone booster system, and thus to validate the concepts for suborbital ballistic flights, it could not begin to match the burnout speed at orbiting altitude given by the Atlas system. Valuable preliminary data on the especially critical accelerations from aborts at intermediate speeds could be duplicated, but Little Joe could lift the capsule only to 100 miles, not put it at that altitude with a velocity approaching 18,000 miles per hour. For this task, a great deal more, some sort of Big Joe was needed. A Jupiter booster might simulate fairly closely the worst reentry heating conditions but ultimately only the Atlas itself could suffice.

Therefore, paralleling the planning of the Little Joe project at Langley, a counterpart test program was inaugurated by the Space Task Group with special assistance from the Lewis Research Center in Cleveland. Whereas Little Joe was a test booster conceived for many different demonstration flight tests, "Big Joe" was the name for a single test flight with a single overriding objective—to learn at the earliest practicable date what would happen when the "steel-balloon" rocket called Atlas powered a ballistic capsule on exit from Earth's atmosphere. Specifically, an experiment matching the velocity, angle of entry, time, and attitude at altitude for reentry from Earth orbit needed to be performed as soon and as exactly as possible by a powered ballistic test flight so that designs for thermal protection might be verified or modified. The Space Task Group was

most anxious about this; the whole manned satellite program was balanced tenuously on the stable thrust of the Atlas and the certain protection of the heatshield.

Public concern over whether the Nation possessed an intercontinental missile was alleviated on November 28, 1958, when an Atlas first flew its designed range—more than 6300 miles—down the Atlantic Missile Range toward Ascension Island. Three weeks later, on December 18, the Atlas scored again with a secretly prepared first launch into orbit of the entire Atlas vehicle (No. 10–B) as a communications relay satellite called "Project Score." Roy Johnson of ARPA claimed he was "sleeping more comfortably each night" after that.[41] In the midst of these demonstrations of the power of the prototype Atlas, NASA Headquarters and the Space Task Group planned to launch the first Atlas test for the space flight program in June or July 1959.

Gilruth appointed Aleck Bond, the former head of the Structural Dynamics Section at Langley, to take the reins as project engineer for Big Joe. Bond began to coordinate, with a real sense of urgency, the work of Langley and Lewis on the prototype capsule and of the Air Force Ballistic Missile Division and Convair/Astronautics on the Atlas propulsion system. Two Big Joe shots were arranged initially, but the second was to be merely insurance against the failure of the first. Although the Lewis laboratory traditionally had been most closely associated with propulsion problems and therefore was the logical center for NASA's first experience with large launch vehicles, neither Lewis direction nor Lewis propulsion experts were directly involved. NASA simply did not have time to learn the intricacies of launching the Atlas itself. Rather, Lewis contributed the expertise to design the electronic instrumentation and the automatic stabilization and control system for the boilerplate capsules being built jointly by the Lewis and Langley shops.

Bond recalled the initial rationale for Big Joe, alias the Atlas ablation test:

> At the time that the Big Joe flight test program was conceived, only limited experimental flight test data existed on the behavior of materials and the dynamics of bodies reentering the earth's atmosphere at high speeds. These data, which evolved from the ballistic missile program, were useful; however, they were not directly applicable to the manned satellite reentry case because of the vast differences in the reentry environment encountered and in the length of time the vehicles were subjected to the environment. There was considerable concern regarding the nature of the motions of a blunt body as it gradually penetrated the earth's atmosphere and began to decelerate. Of similar concern was the lack of after-body heating measurements and knowledge of integrity of ablation materials when exposed to the relatively low level, long duration heat pulse which is characteristic of the reentry of bodies with low ballistic parameters . . . entering the earth's atmosphere at shallow entry angles.[42]

Although for Big Joe the Task Group could center its attention on the capsule, whereas for Little Joe it had to develop the booster as well, the design and

development problems for Big Joe still were sufficient to cause slippage in the scheduled launch date from early to late summer in 1959. To launch and recover the capsule safely would require very extensive familiarization with new procedures. Central among the primary objectives for Big Joe were the twin needs to determine the performance of the thermal protection materials and to learn the flight dynamics of the spacecraft during reentry. Many critical decisions for the project depended upon early, reliable data on the heatshield, the afterbody radiative shingling, and the dynamic stability of the "raindrop" configuration during the craft's trajectory back through the atmosphere.[43]

Also necessary were evaluations of the aerodynamic and thermodynamic loads on the capsule all along its flight path and of the operation of its automatic attitude control system. But certainly nothing was more important in the fall of 1958 than the need to settle the technical controversy over the heat sink versus ablation principles for the heatshield. Whether to use absorbing or vaporizing materials to shield the astronaut from reentry heating was one of the few major problems remaining to be solved when the manned satellite project was established.

## Heat Sink Versus Ablation

Since the peak heating rates for this blunt-body, high-drag configuration were expected to be one whole order of magnitude less than those experienced by ballistic missiles, no one competent to judge the issue now considered the "thermal barrier" problem insoluble. Rather, it had been proven to be no more than a "thermal thicket." Since the mid-fifties, various civilian and military experimental teams had studied the reentry problems for ballistic missile warheads, but only part of this research data was applicable to the different case of the spacecraft. Army and Vitro Corporation reentry experiments using ablation materials (such as graphite, teflon, nylon, or lucite) had already demonstrated that Jupiter nose cones worked quite well as ablators. But NACA preferred to rely on the successful prior experience of the Air Force with heat-sink metals, particularly copper, for early Thor nose cones. The results of these thermodynamic studies in materials science were contradictory, or at least inconclusive. So the manned satellite project began life officially in October without a commitment to either method of heat shielding, but with a definite preference for Faget's prejudice.[44]

Gilruth, Faget, and other members of the Space Task Group since March 1958 had been leaning toward the heat sink. A 600-pound metallic heat sponge might be a little heavier but it would be more reliable than a ceramic heat dissipator, for the simple reason that there was more industrial experience with fabricating refractory metals than with molding and bonding ablation materials. Some officials were convinced by the Navy's successful use of a lightweight beryllium heat sink on Polaris flight tests that beryllium was the answer. The heat sink method also was thought to have the considerable advantage over ablating materials of creating less of a "plasma sheath"—the envelope of ionized air

generated by the friction of atmospheric braking. Telemetry and communications blackouts from this phenomenon might be troublesome. Pending further study, the Task Group and Silverstein decided to retain the original specification that a beryllium heatshield be provided by the capsule contractor. Requiring all the bidders to assume a beryllium shield should give a fairer evaluation of their proposals. Until Big Joe could test the ablation technique, no final decision would be made.[45]

Ablation technology, imprecise by nature, was neither well understood nor very highly sophisticated as yet, whereas the metallography of heat sink materials was straightforward, and the thermodynamics of metals was deducible. Faget believed there would be no intrinsic weight penalty for using a metal shield; the difficulty of ditching a hot shield without danger had yet to be solved. There was no disposition to ignore ablation in favor of heat sink. Big Joe was conceived to resolve the problem. By late November, when Aleck Bond took charge of it, his presumption was that Big Joe would provide the definitive test of an ablation heatshield.

Rocketry was not the only means considered for accomplishing high-altitude qualification tests at the beginning of the program. On their own initiative in the summer of 1958, Jerome Hammack, John B. Lee, Joe W. Dodson, and other Langley engineers had begun a modest program of parachute and stability trials by dropping boilerplate capsule models from C–130 transports provided by the Air Force. Balloon flights, however, seemed to promise even more effective and economical means of qualifying by "space-soaking" the complete capsule and its associated systems. From the Montgolfier brothers in the 1780s to David G. Simons' Manhigh ascents in 1957 and the contemporary Strato-Lab project of the Navy, ballooning had always been an attractive way to pierce the vertical dimension.[46]

Believing that the environmental conditions at extreme altitude could be experienced more easily than they could be simulated in vacuum chambers on Earth, the Space Task Group proceeded with plans to launch balloons carrying ballistic capsules as gondolas. Tests of instrumentation, retrorockets, drogue and main parachute systems, and recovery procedures, plus pilot orientation and training, might be done within a year's time by lighter-than-air ascents. Contracts were let to the Weather Bureau, the Office of Naval Research, and the Air Force Cambridge Research Center for planning this flight support program.[47]

No sooner had these feasibility studies been started than the Space Task Group discovered how intricate, vast, and expensive had become stratospheric sounding technology in recent years. The popular craze over Unidentified Flying Objects during the fifties had been caused partly by atmospheric and cosmic-ray research with floating objects, enormous Mylar plastic gas bags drifting around at high altitudes. Preliminary balloon flights for the manned satellite project threatened to become much more expensive than had been originally anticipated.[48]

Contract planning, booster procurement, and the need for specialized help

from the military services were central concerns of NASA and the Space Task Group during their first three months of existence. The possibility of friction in management relations between NASA and the Defense Department was also recognized as a potential problem. To facilitate coordinated work and plans, STG needed in-house representatives in uniform. Efficient administration demanded liaison officers to serve as single points of contact between STG and each of the military services. So in December orders were cut for Lieutenant Colonel Keith G. Lindell of the Air Force, Lieutenant Colonel Martin L. Raines of the Army, and Commander Paul L. Havenstein of the Navy to report to the Space Task Group for this function.

In general, relations between NASA and the Department of Defense had proceeded quite amicably since the drafting of a "Memorandum of Understanding" in September by the Joint Manned Satellite Panel.[49] However, with so much initiative being taken by the Space Task Group, there was danger that the concurrent actions of NASA Headquarters and STG might cause some frustrations and confusions in the Pentagon and among military contractors. NASA was still too young for its STG to be known. At this stage most of the planning for budgeting, procurement, tracking, and recovery operations had to be done in Washington; NASA Headquarters was carefully guarding its prerogative of conducting interagency business.[50] Cooperation between Defense and NASA, and between STG and its own Headquarters, was good, if not idyllic, during the first 100 days. Nowhere was this more obvious than in astronaut selection.

## Project Astronaut?

Preliminary procedures for pilot selection had been worked out by the aeromedical consultants attached to the Space Task Group at Langley during November. Their plan called for a meeting with representatives from industry and the services to nominate a pool of 150 men from which 36 candidates would be selected for physical and psychological testing. From this group 12 would be chosen to go through a nine-month training and qualification program, after which six finally would be expected to qualify.[51]

On the basis of this plan, Donlan from Langley, and North in Washington, together with Allen O. Gamble, a psychologist on leave from the National Science Foundation, drafted civil service job specifications for individuals who wished to apply for the position of "Research Astronaut-Candidate." One of the early plans outlined very well the original expectations of NASA and STG on the type of man thought necessary. NASA Project A, announcement No. 1, dated December 22, 1958, was a draft invitation to apply for the civil service position of research astronaut-candidate "with minimum starting salary range of $8,330 to $12,770 (GS–12 to GS–15) depending upon qualifications." This document called the manned ballistic satellite program "Project Astronaut," and the first section described the duties of the astronaut:

> Although the entire satellite operation will be possible, in the early phases, without the presence of man, the astronaut will play an important role during the flight. He will contribute by monitoring the cabin environment and by making necessary adjustments. He will have continuous displays of his position and attitude and other instrument readings, and will have the capability of operating the reaction controls, and of initiating the descent from orbit. He will contribute to the operation of the communications system. In addition, the astronaut will make research observations that cannot be made by instruments; these include physiological, astronomical and meteorological observations.[52]

Only males between 25 and 40 years of age, less than 5 feet 11 inches in height, and with at least bachelor's degrees were to be considered. Stringent professional experience or graduate study requirements specified five patterns of career histories most desirable. Candidates who had either three years of work in any of the physical, mathematical, biological, or psychological sciences, or who had three years of technical or engineering work in a research and development program or organization might apply. Or anyone with three years of operation of aircraft, balloons, or submarines, as commander, pilot, navigator, communications officer, engineer, or comparable technical position, would be eligible, as would persons who had completed all requirements for the Ph.D. degree in any appropriate field of science or engineering plus six months of professional work. In the case of medical doctors, six months of clinical or research work beyond the license and internship or residency would be required. Furthermore, the job qualifications required proof that applicants had demonstrated recently their "(a) willingness to accept hazards comparable to those encountered in modern research airplane flight; (b) capacity to tolerate rigorous and severe environmental conditions; and (c) ability to react adequately under conditions of stress or emergency." The announcement added:

> These three characteristics may have been demonstrated in connection with certain professional occupations such as test pilot, crew member of experimental submarine or arctic or antarctic explorer. Or they may have been demonstrated during wartime combat or military training. Parachute jumping or mountain climbing or deep sea diving (including SCUBA) whether as occupation or sport, may have provided opportunities for demonstrating these characteristics, depending upon heights or depths obtained, frequency and duration, temperature and other environment conditions, and emergency episodes encountered. Or they may have been demonstrated by experience as an observer-under-test for extremes of environmental conditions such as acceleration, high or low atmospheric pressure, variation in carbon dioxide and oxygen concentration, high and low ambient temperatures, etc. Many other examples could be given. It is possible that the different characteristics may have been demonstrated by separate types of experience.

Finally, as a last check on ruling out the "lunatics" who might send in crank applications, this proposed plan for astronaut selection required that each applicant have the sponsorship of a responsible organization. A nomination form

appended to this announcement would have required 17 multi-point evaluations of the nominee by some official of the sponsoring institution.

Clearly this astronaut selection plan was sober enough and stringent enough to ensure an exceptionally high quality applicant, but the plan itself was not approved and had to be abandoned. President Eisenhower during the 1958 Christmas holidays decided that the pool of military test pilots already in existence was quite sufficient a source from which to draw. Since certain classified aspects would inevitably be involved, military test pilots could most conveniently satisfy security considerations.[53]

Although some in NASA regretted the incongruity of allowing volunteers for the civilian manned space program to be drawn only from the military, the decision that the services would provide the candidates greatly simplified pilot selection procedures. A meeting held at NASA Headquarters during the first week of January brought together W. Randolph Lovelace II, Brigadier General Don D. Flickinger, Low, North, Gilruth, and several other members of the Space Task Group. There the elaborate civil service criteria for selection were boiled down to a seven-item formula:

1. Age—less than 40.
2. Height—less than 5 feet, 11 inches.
3. Excellent physical condition.
4. Bachelor's degree or equivalent.
5. Graduate of test pilot school.
6. 1500 hours total flying time.
7. Qualified jet pilot.

When these criteria were given to the Pentagon, service record checks revealed more than 100 men on active duty who appeared to be qualified. The military services were pleased to cooperate in further screening. NASA was relieved not to have to issue an open invitation, and STG was pleased to have Headquarters' aid in the selection.[54]

Contrary to the feeling expressed in some quarters, even among experimental test pilots, that the ballistic capsule pilot would be little more than "spam in a can," most members of STG believed from the beginning that their pilots would have to do some piloting. As George Low explained their views to Administrator Glennan, "These criteria were established because of the strong feeling that the success of the mission may well depend upon the actions of the pilot; either in his performance of primary functions or backup functions. A qualified jet test pilot appeared to be best suited for this task." [55] Exactly how much "piloting," in the traditional sense, man could do in orbit was precisely the point in issue.

The least technical task facing NASA and its Space Task Group in the fall of 1958 was choosing a name or short title for the manned satellite project. Customarily project names for aircraft and missiles were an administrative convenience best chosen early so as to guarantee general usage by contractors, press,

and public. Langley had earlier suggested to Headquarters three possible emblems or seals for the use of NASA as a whole: one would have had Phaeton pulling Apollo across the sky; another would have used the Great Seal of the United States encompassed by three orbital tracks; and a third proposed a map of the globe circled by three orbits. These proposals, as well as the name suggested by Space Task Group for the manned satellite project, lost out to symbols considered more appropriate in Washington. "Project Astronaut," preferred at first by Gilruth to emphasize the man in the satellite, was overruled largely because it might lead to overemphasis on the personality of the man.[56]

Silverstein advocated a systemic name with allegorical overtones and neutral underpinnings: The Olympian messenger Mercury, denatured by chemistry, advertising, an automobile, and Christianity, was the most familiar of the gods in the Greek pantheon to Americans. Mercury, alias Hermes, the son of Zeus and grandson of Atlas, with his winged sandals and helmet and caduceus, was too rich in symbolic associations to be denied. The esteemed Theodore von Kármán had chosen to speak of Mercury, as had Lucian of Samosata, in terms of the "reentry" problem and the safe return of man to Earth.[57]

Had a mythologist been consulted, perhaps the additional associations of Mercury with masterful thievery, the patronage of traders, and the divinity of commerce would have proven too humorous. But "Mercury," Glennan and Dryden agreed on November 26, 1958, was the name most appropriate for the manned satellite enterprise.[58]

Greeks might worry about whether Mercury would function in his capacity as divine herald or as usher to the dead, but Americans, like the Romans, could be trusted not to worry. On Wright Brothers' Day, December 17, 1958, 55 years after the famous flights at Kitty Hawk, North Carolina, Glennan announced publicly in Washington that the manned satellite program would be called "Project Mercury." [59]

# VI

## From Design into Development

(JANUARY–JUNE 1959)

FROM dreams into definitions and from design into development, the idea for a manned satellite was growing toward fruition. During the first half of 1959, the Space Task Group (STG) guided the translation of its conceptual designs into detailed developmental plans for the molding of hardware. Creating an engineering program, planning precisely the flight missions, organizing men, money, and material to fulfill those missions, and establishing technical policy and managerial responsibility were the prime necessities of the moment. But this year began with the realization of a Russian "dream," *Mechta*.

On January 2, 1959, the Soviets announced they had successfully launched a rocket toward the Moon, the final stage of which weighed 3245 pounds, including almost 800 pounds of payload instrumentation inside its spherical shell. The Soviet *Mechta,* also popularly called *Lunik I,* was the first man-made object to attain the 25,000-mile-per-hour speed needed to break away from Earth's gravitational field. By comparison the United States Moon probe *Pioneer III*, launched by a four-stage Jupiter called Juno II on December 6, 1958, had weighed 13 pounds and attained a velocity of 24,000 miles per hour. And though it missed its target, *Lunik I* flashed past Earth's natural satellite to become the first successful "deep space" (i.e., translunar) probe and the first man-made artifact to become a solar satellite.[1]

While *Mechta* presumably went into solar orbit, and even while many incredulous Americans refused to accept this impressive claim, NASA mobilized for the national effort to catch up with the Soviets in propulsion and guidance, and in progress toward manned space flight. The project named Mercury embodied the latter half of those hopes.

Robert R. Gilruth and his STG associates at Langley, together with Abe Silverstein and others in Washington, plunged knowingly into one of the greatest engineering adventures of all time. Somewhat self-conscious in the role of men of action setting out to do what had never been done before, they tried to match means to their ends without too much introspection and by avoiding useless

worries over comparative scores in the space race. Like all good engineers, they were also professors of efficiency. They committed themselves to do their unique task as effectively, economically, and quickly as possible. But the inexorable conflict between the novelty of the experiment and the experience with novelty that alone can lead to efficiency they had to accept as an occupational hazard. Two of their ideals—to perform orbital flight safely and to perform it with economy—were embodied in preliminary designs for Project Mercury long before those same ideals became obligations during the development of the program. Their third ideal—timeliness—gradually became crushed between performance and cost considerations.

In the hectic three months of planning and procurement from September 1958 to January 1959, the original "objectives and basic plan" for Project Mercury gradually clarified by abbreviation to an itemized list. Continued reiteration throughout preliminary development (January through June 1959) finally reduced the aims, attitudes, and means of the Space Task Group to a set of nominative formulas used again and again as "Slide No. 1" in briefings:

*Objectives*
1. Orbital flight and recovery
2. Man's capabilities in environment

*Basic Principles*
1. Simplest and most reliable approach
2. Minimum of new developments
3. Progressive build-up of tests

*Method*
1. Drag vehicle
2. ICBM booster
3. Retrorocket
4. Parachute descent
5. Escape system

Reduced to this form by July 1959, the basic doctrine for Project Mercury remained essentially unchanged throughout the entire life of the program. Although the managers of Mercury found this a source of considerable pride, they were forced to make certain departures from their basic principles and to refine their methods continually.[2] The techniques and technology for landing, for example, were not specified this early. The efforts to ensure a safe touchdown, on water instead of land, became a critical concern over a year later.

### Brickbat Priority

From the beginning STG had sought to obtain the Nation's highest priority for the manned satellite program. But the White House, Congress, and NASA Headquarters at first regarded as equally important the development of a "$10^6$,"

or one-million-pound-thrust, booster engine, and the elaboration of space sciences through the continuation of instrumented satellite programs similar to Vanguard. Hugh L. Dryden initiated a request to the Department of Defense as early as November 14, 1958, to put the "manned satellite and the one-million-pound-thrust engine" in the DOD Master Urgency List alongside the Minuteman and Polaris weapon systems. But the National Aeronautics and Space Council (NASC) had deferred this request on December 3, pending a scheduled meeting the next week of the Civilian-Military Liaison Committee (CMLC). The Space Council did recommend that NASA assign its highest in-house priority to Project Mercury. When it met, the Liaison Committee recommended the "DX," or highest industrial procurement priority, for the manned satellite. They assumed that the Vanguard and Jupiter-C projects would be dropped from that category and that the million-pound-thrust engine would be assigned the next lower, or a "DO," priority.[3]

New additions to the DX list required the approval of the National Security Council, but earlier that body had delegated authority to the Secretary of Defense to decide on top priorities for satellite systems. Secretary Neil H. McElroy and the Joint Chiefs of Staff received the Liaison Committee's recommendations for a new Master Urgency List on December 17. NASA Administrator T. Keith Glennan protested to William M. Holaday, the Pentagon's Director of Guided Missiles and chairman of the Liaison Committee, that not only Mercury but the big new booster, to become known in February as the Saturn, should have top priority. McElroy therefore directed Holaday to review the entire DX category before deciding what to do about the dual NASA requests for the so-called "brickbat," or highest, priority rating.[4] Here matters stood at the end of the year.

For these reasons, financial allowances for extensive (and expensive) overtime work and the authorization for preferential acquisition of scarce materials were delayed well into 1959. Maxime A. Faget's optimistic belief before the program started that a man might possibly be placed in orbit within 18 months, or during the second quarter of the calendar year 1960, depended upon the immediate assignment of the Nation's highest priority to Mercury—and an enormous amount of the best possible luck! One of the first official estimates of the launch schedule for STG, made by Christopher C. Kraft, Jr., in early December for the Air Force Missile Test Center at Cape Canaveral predicted concurrent development, qualification, and manned orbital flights from April through September in 1960.[5] This "guesstimate" was likewise predicated on an immediate Defense Department order to allow Project Mercury to compete "on a non-interference basis" with the military missile programs in obtaining critical "off-the-shelf" components, particularly electronic and guidance items.

By the first of the new year, it was fairly clear that the large Saturn booster would be continued by the Army's Wernher von Braun team and that the Defense Department was not about to release von Braun and his associates to NASA. Glennan, Dryden, and Silverstein had given Project Mercury the highest priority

within NASA itself, but among industrial suppliers and the Defense Department it ranked second to several more urgent and competing demands. By March 1959, definite evidence of equipment and material supply shortages accumulated. The new prime contractor warned of delivery schedule slippages resulting from Mercury's DO rating. Holaday's reports were favorable toward Mercury, and Glennan compromised on the "$10^6$-engines." For the Advanced Research Projects Agency (ARPA) had directed the Army Ordnance Missile Command and the Air Force Ballistic Missile Division, respectively, to start independent development of both a clustered first-stage booster (the Saturn) and a single-chamber rocket engine (the F–1) able to generate about 1,500,000 pounds of thrust.[6]

So NASA finally presented a united front with the Defense Department to the President and Congressional committees. On April 27, 1959, Eisenhower himself approved the request for the "brickbat" procurement rating for Mercury. The prime contract and most of the major subcontracts for the space capsule had been let well before May 4, when Mercury was officially listed in the topmost category on the Master Urgency List.[7] But the attendant privilege of not having to seek the lowest bidder on every major item bought was probably less important to the development of the program than the added prestige and support the DX rating brought to Mercury within the aerospace industry and among the military services.

During the first quarter of 1959, confusion reigned in Washington aerospace circles as too many missile czars, too many space projects, and too many agencies clamored for more funds and support. But journalists, scientists, and humanitarians applauded the successes of the Navy-NASA *Vanguard II,* a tiny weather satellite; of the Air Force's *Discoverer I,* first satellite in polar orbit; and of the Army-NASA *Pioneer IV,* which managed to duplicate *Mechta*'s escape velocity. As a deep-space probe and the first U.S. solar satellite, *Pioneer IV,* launched March 3, was magnificently instrumental in expanding man's knowledge of the plurality of the Van Allen radiation belts and of the "solar winds," or radiation storms, that permeate interplanetary space. Glennan had resolved to identify all NASA booster rockets with the name "United States" only, but other rocket agencies within the government were unlikely to follow suit. In the midst of all this, Project Mercury seemed still an obscure conception to the public. Roy W. Johnson of ARPA called it "very screwball" when first proposed; by the end of March he said, "It looks a little less screwball now." [8]

Meanwhile, within STG itself, the most urgent task in getting on with the program had already been accomplished by the end of 1958. On December 29 the Task Group had completed its technical assessments of the industrial proposals for manufacturing the capsule and its subsystems. Eleven complete proposals had been received. The narrowing of the field of possible manufacturers was facilitated by the fact that so many alternate configurations were submitted. Faget had invited the bidders "to submit alternate capsule and configuration designs if you so desire, provided that you incorporate the retrorocket principle, the non-

lifting principle and the non-ablating heat sink principle. You are not limited to this particular approach only."[9] But some of the bidders had taken him altogether too literally in this statement.

### Awarding the Prime Contract

During the first week in January, another group of men, led by Carl Schreiber at NASA Headquarters, evaluated the procurement aspects of the competitive proposals. This Management, Cost, and Production Assessment Committee was required to rank only eight companies, because four had been disqualified on purely technical grounds. By January 6, four companies were reported to the Source Selection Board as having outstanding management capabilities for the prime contract. But in the final analysis Abe Silverstein and the six members of his board had to decide between only two firms with substantially equal technical and managerial excellence: Grumman Aircraft Engineering Corporation and McDonnell Aircraft Corporation. The NASA Administrator himself eventually explained the principal reason for the final choice:

> The reason for choosing McDonnell over Grumman was the fact that Grumman was heavily loaded with Navy projects in the conceptual stage. It did not appear wise to select Grumman in view of its relatively tight manpower situation at the time, particularly since that situation might be reflected in a slow start on the capsule project regardless of priority. Moreover, serious disruption in scheduling Navy work might occur if the higher priority capsule project were awarded to Grumman.[10]

NASA informed McDonnell on January 12 that it had been chosen the prime contractor for the Mercury spacecraft. Contract negotiations began immediately; after three more weeks of working out the legal and technical details, the stickiest of which was the fee, the corporation's founder and president, James S. McDonnell, Jr., signed on February 5, 1959, three originals of a contract.[11] This document provided for an estimated cost of $18,300,000 and a fee of $1,150,000. At the time, it was a small part of McDonnell's business and a modest outlay of government funds, but it officially set in motion what eventually became one of the largest technical mobilizations in American peacetime history. Some 4000 suppliers, including 596 direct subcontractors from 25 states and over 1500 second-tier subcontractors, soon came in to assist in the supply of parts for the capsule alone.[12]

The prime contract was incompletely entitled "Research and Development Contract for Designing and Furnishing Manned Satellite Capsule." The omission of an article before the word "manned" and the lack of the plural form for the word "capsule" prefigured what was to happen within the next five months. The original contract began evolving with the program, so that instead of 12 capsules of identical design, as first specified, 20 spacecraft, each individually designed for a specific mission and each only superficially like the others, were produced by McDonnell. Contract change proposals, or "CCPs," as they were

known, quickly grew into supplemental agreements that were to overshadow the prime contract itself.[13]

The relative roles of STG and McDonnell engineers in pushing the state of the art from design into construction are difficult to assess. Cross-fertilization of ideas and, after the contract was awarded, almost organically close teamwork in implementing them characterized the STG-McDonnell relationship. For a year before the company's selection as prime contractor, original design studies had been carried on with company funds. From a group of 12 engineers led by Raymond A. Pepping, Albert Utsch, Lawrence M. Weeks, and John F. Yardley in January 1958, the Advanced Design section at McDonnell grew to about 40 people by the time the company submitted its proposal to NASA. The proposal itself stated that the company already had invested 32 man-years of effort in the design for a manned satellite, and the elaborate three-volume prospectus amply substantiated the claim.[14]

In STG's 50-page set of final "Specifications for a Manned Space Capsule," drawn up in November, Faget and associates had described in remarkable detail their expectations of what the capsule and some 15 subsystems should be like. Now the McDonnell production engineers set about expanding the preliminary specifications, filling gaps in the basic design, preparing blueprints and specification control drawings, and retooling their factory for the translation of ideas into tangible hardware. Specification S–6 had enjoined the contractor to provide at his plant as soon as possible a mockup, or full-scale model made of plywood and cardboard, of the capsule system. With high expectations the Task Group awaited March 17, the date by which McDonnell had promised to have ready their detailed specifications and a dummy Mercury capsule and escape tower.[15] But the debut was not to be achieved easily.

Before the company could finish building the mockup, at least two technical questions affecting the configuration had to be resolved: one was the type of heatshield to be used; the other was the exact design for the escape system. A third detail, the shape of the antenna canister and drogue chute housing atop the cylindrical afterbody, was also tentative when STG and McDonnell engineers began to work together officially on January 12, 1959.[16]

### Heatshield Resolution

To begin with, all capsule proposals had been evaluated on the basis of a beryllium heat sink, but the search for an ablating heatshield continued concurrently. George M. Low reported the tentative resolution of this conflict in late January:

> At a meeting held at Langley Field on January 16 (attended by Drs. Dryden and Silverstein), it was decided to negotiate with McDonnell to design the capsule so that it can be fitted with either a beryllium heat sink or an ablation heat shield. It was further decided that McDonnell should supply

> a specified number (of the order of eight) ablation shields and a specified number (of the order of six) beryllium heat sinks. It is anticipated that flights with both types of heat protection will be made . . . . In case of a recovery on land, the capsule with a beryllium heat sink will require cooling; this is accomplished by circulating air either between the heat sink and the pressure vessel, or by ventilating the pressure vessel after impact.[17]

Regarding the escape system, McDonnell's proposal had carefully weighed the relative merits of STG's pylon, or tower, type of tractor rocket with the alternative idea, which used three sets of dual-pod pusher rockets, similar to JATO bottles, along either side of three fins at the base of the capsule. McDonnell chose the latter system for its design proposal, but the STG idea prevailed through the contract negotiations, because the Redstone was calculated to become aerodynamically unstable with the pod-type escape system, and the Atlas would likely be damaged by jettisoning the pod fins.[18] The escape system for an aborted launch was intimately interrelated with the problems of the heatshield and of the normal, or nominal, landing plans. By mid-March Robert F. Thompson's detailed proposals for a water landing helped clarify the nature of the test programs to be conducted.

While McDonnell agreed to design the capsule so that it could be fitted alternatively with either a beryllium heat sink or an ablation heatshield, the prime contractor farmed the fabrication of these elements to three subcontractors: Brush Beryllium Company of Cleveland was to forge six heat-sink heatshields; General Electric Company and Cincinnati Testing and Research Laboratory (CTL) were to fabricate 12 ablation shields. The Space Task Group relied on Andre J. Meyer, Jr., to monitor this critical and sensitive problem, the solution to which would constitute the foremost technological secret in the specifications for the manned capsule.

Meyer, one of the original STG members from Lewis in Cleveland, had been commuting to Langley for 10 months. He soon discovered a bottleneck in the industrial availability of beryllium. Only two suppliers were found in this country; only one of these, Brush, had as yet successfully forged ingots of acceptable purity. But ablation technology was equally primitive, so plans had to be made on dual tracks. Meyer had had much experience with laminated plastics for aircraft structures. He had previously learned, in consultations with the Cincinnati Testing Laboratory, how to design a "shingle layup" for fabrication of an ablation heatshield. While collecting all available information on both the ablative plastic and the beryllium industries, Meyer listened to the Big Joe project engineers, Aleck C. Bond and Edison M. Fields. They argued for ablation, specifically for a fiber glass-phenolic material, as the primary heat protection for the astronaut. Before moving to Virginia in February, Meyer consulted on weekends with Brush Beryllium in Cleveland, watching its pioneering progress in forging ever larger spherical sections of the exotic metal, which is closely akin to the precious gem emerald. But Meyer, along with Bond and Fields, grew more skeptical

of the elegant theoretical deductions that supported the case for beryllium. Mercury would have a shallow angle of entry and consequently a long heat duration and high total heat; they worried about the possibility that any heat sink might "pressure cook" the occupant of the capsule. So Meyer, using CTL's shingle concept, perfected his designs for an ablative shield.[19]

There was something basically appealing about the less tidy ablation principle, something related to a basic principle in physics, where the heat necessary to change the state (from solid to liquid to gas) of a material is vastly greater than the heat absorbed by that material in raising its temperature by degrees. Meyer became convinced by March that beryllium would be twice as expensive and only half as safe. Consequently, Meyer and Fields concentrated their efforts on proving their well-grounded intuition that ablation technology could be brought to a workable state before the Big Joe shot in early summer.[20]

While lively technical discussions over ablation versus heat sink continued through the spring, the fact that Mercury officials had committed Big Joe to the proof-testing of an ablative shield also rather effectively squelched any further attempts at scientific comparisons. Whereas in January Paul E. Purser recorded that "we will procure both ablation and beryllium shields . . . and neither will be 'backup,' they will be 'alternates,' " by the end of April technological difficulties in manufacturing the prototype ablation shields became so acute as to monopolize the attention of cognizant STG engineers.[21]

Glennan and Silverstein in Headquarters therefore directed continuation of the heat sink development as insurance, while STG gradually consigned the alternative beryllium shield to the role of substitute even before the fiber glass-phenolic shield had proved its worth. By mid-year of 1959, apparently only the Brush Beryllium Company still felt confident that the metallic heat sponge was a viable alternative to the glass heat vaporizer in protecting the man in space from the fate of a meteor. The complicated glass-cloth fabricating and curing problems for the ablation shield were mostly conquered by July. John H. Winter, the heatshield project coordinator at the Cincinnati Testing Laboratory, delivered his first ablation shield to NASA in Cleveland on June 22 under heavy guard.[22]

The critical question of whether to jettison the heatshield was active early in 1959. If the shield were a heat sink, it would be so hot by the time it reached the lower atmosphere that to retain it after the main parachute had deployed would be hazardous to the pilot. Also in case of a dry landing such a hot sponge could easily start a prairie or forest fire. On the other hand, a detachable shield would add complexity to the system and increase the risk of its loss before performing its reentry job. In one of the early airdrops a jettisoned shield actually went into "a falling leaf pattern after detachment. It glided back and collided with the capsule, presenting an obvious potential hazard for the pilot in his vehicle late in the reentry cycle." [23] This incident prompted the decision that the heatshield would be retained, although it might very well be lowered in the final moments of the flight if it could help attenuate impact. The memory of this early collision

after jettisoning continued to haunt STG engineers until they rejected the beryllium heat-sink shield altogether.

Although the heatshield problem was highly debatable at the inception of the project, there was consolation in the fact that at least two major development areas were virtually complete. The two items considered frozen at the end of January 1959 were the external configuration of the capsule, except for the antenna section, and the form-fitting couch in which the astronaut would be able to endure a force of 20 g or more, if it should come to that.[24] The Space Task Group was pleased to have something as accomplished fact when so many other areas were still full of uncertainties.

To George Low's ninth weekly status report for Administrator Glennan on STG's progress and plans for Project Mercury was appended a tabular flight test schedule that summarized the program and mission planning as envisioned in mid-March 1959. Five Little Joe flights, eight Redstone, two Jupiter, ten Atlas flights, and two balloon ascents were scheduled, the categories overlapping each other from July 1959 through January 1961. The first manned ballistic suborbital flight was designated Mercury-Redstone flight No. 3, or simply "MR–3," to be launched about April 26, 1960. And the first manned orbital flight, designated Mercury-Atlas No. 7, or "MA–7," was targeted for September 1, 1960. After that, STG hoped to fly several more, progressively longer orbital missions, leading finally to 18 orbits or a full day for man in space. Although merely a possible flight test plan, this schedule set a superhuman pace and formed the basis for NASA's earliest expectations.[25]

## Applied Research

By March 1, Langley Research Center was formally supporting the Task Group in conducting five major programs of experimentation. The first was an airdrop study, begun the previous summer, to determine the aerodynamic behavior of the capsule in free fall and under restraint by various kinds of parachute suspension. By early January more than a hundred drops of drums filled with concrete and of model capsules had produced a sizable amount of evidence regarding spacecraft motion in free falls, spiraling and tumbling downward, with and without canopied brakes, to impacts on both sea and land.[26] But what specific kind of a parachute system to employ for the final letdown remained a separate and debatable question.

A second group of experiments sought to prove the workability of the escape system designs in shots at Wallops Island. On March 11 the first "pad abort," a full-scale escape-rocket test, ended in a disappointing failure. After a promising liftoff the Recruit tractor-rocket, jerking the boilerplate spacecraft skyward, suddenly nosed over, made two complete loops, and plunged into the surf.

So disappointing was this test that for several weeks the fin-stabilized pod rocket escape system was almost reinstituted.[27] Three Langley engineers, cha-

grined by this threat to their work, conducted a full postmortem following the recovery of the capsule. They blamed the erratic behavior on a graphite liner that had blown out of one of the three exhaust nozzles. Willard S. Blanchard, Jr., Sherwood Hoffman, and James R. Raper, working frantically for a month, were able to perfect and prove out their design of the escape rocket nozzles by mid-April. At the same time they improved the pitch-rate of the system by deliberately misaligning the pylon about one inch off the capsule's centerline.[28]

The third applied research program was a series of exhaustive wind-tunnel investigations at Langley and at the Ames Research Center to fill in data on previously unknown values in blunt-body stability at various speeds, altitudes, and angles of attack. Model Mercury capsules of all sizes, including some smaller than .22 rifle bullets, were tested for static-stability lift, drag, and pitch in tunnels. Larger models were put into free flight to determine dynamic-stability characteristics. Vibration and flutter tests were conducted also in tunnels. The variable location of the center of gravity was of critical interest here, as was also the shifting meta-center of buoyancy.[29]

Using the thunderous forced-draft wind tunnels at Langley and Ames, aeronautical research engineers pored over schlieren photographs of shock waves, windstreams, boundary layers, and vortexes. Most of the NASA tunnel scientists had long been airplane men, committed to "streamlined" thinking. Now that H. Julian Allen's blunt-body concept was to be used to bring a man back from 100 miles up and travelling about five miles per second, both thought and facilities had to be redirected toward making Mercury safe and stable.

Albin O. Pearson was one such airplane-tunnel investigator who was forced to change his way of thinking and his tools by the ever higher mach number research program for Mercury. Pearson worked at Langley coordinating all aerodynamic stability tests for Mercury with blunt models at trans-, super-, and hypersonic speeds. While exhausting the local facilities for his transonic static stability studies, Pearson arranged for Dennis F. Hasson, Steve Brown, Kenneth C. Weston, and other Langley, STG, and McDonnell aerodynamicists to use various Air Force tunnels at the Arnold Engineering Development Center, in Tullahoma, Tennessee. Beginning on April 9, 1959, a number of Mercury models and escape configurations were tested in the 16-foot propulsion wind tunnel and 40-inch (mach 22 capability) "Hot Shot" facility at Tullahoma. During the next 16 months a total of 103 investigations utilizing 28 different test facilities were made in the wind-tunnel program.[30]

A fourth experiment program concerned specifically the problem of landing impact. Ideally touchdown should occur at a speed of no more than 30 feet per second, but how to ensure this and how to guard against impacts in directions other than vertical were exasperating problems. Landing-loads tests in hydrodynamics laboratories for the alternative water landing had only begun. The anticipated possibility of a ground impact, which would be far more serious, demanded shock absorbers far better than any yet devised. Although there was

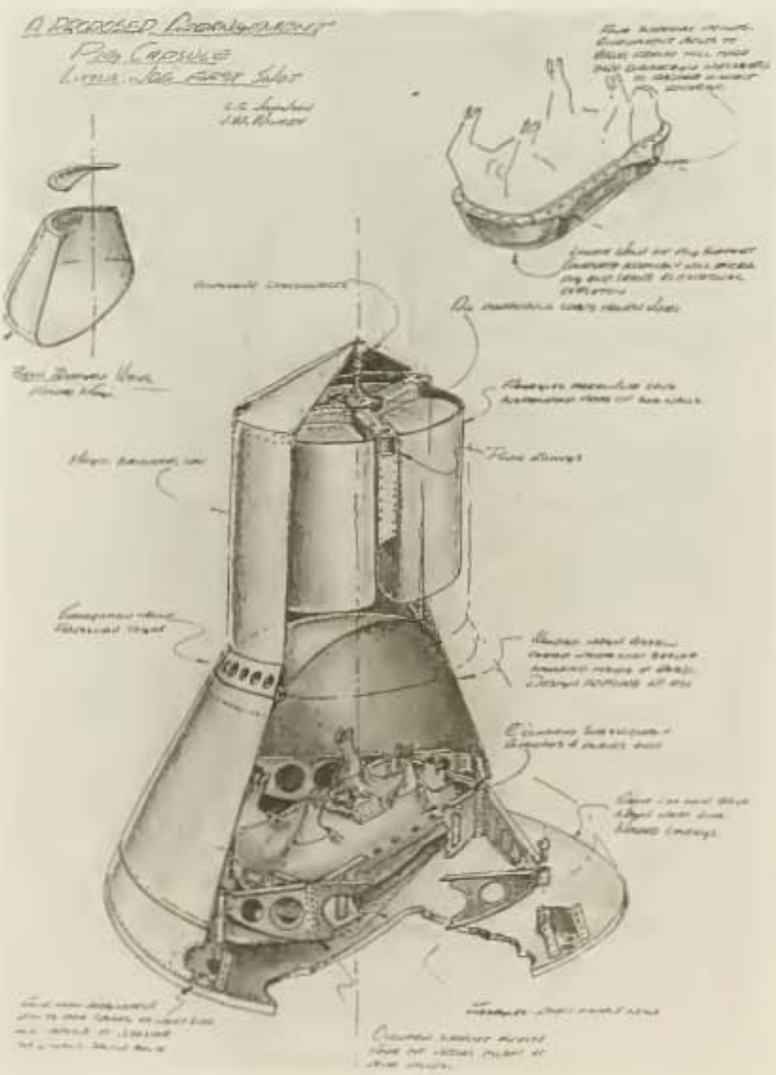
still no assurance that the astronaut inside a floating capsule could crawl out through the throat without its capsizing, this egress problem was less demanding at the moment than the need for some sort of crushable material to absorb the brunt of a landing on land.

Through April and May, McDonnell engineers fitted a series of four Yorkshire pigs into contour couches for impact landing tests of the crushable aluminum honeycomb energy-absorption system. These supine swine sustained acceleration peaks from 38 to 58 g before minor internal injuries were noted. The "pig drop" tests were quite impressive, both to McDonnell employees who left their desks and lathes to watch them and to STG engineers who studied the documentary movies. But, still more significant, seeing the pigs get up and walk away from their forced fall and stunning impact vastly increased the confidence of the newly chosen astronauts that they could do the same. The McDonnell report on these experiments concluded, "Since neither the acceleration rates nor shock pulse amplitudes applied to the specimens resulted in permanent or disabling damage, the honeycomb energy absorption system of these experiments is considered suitable for controlling the landing shock applied to the Mercury capsule pilot." [31]

Fifth, and finally, other parachute experiments for spacecraft descent were of major concern in the spring of 1959, because neither the drogue chute for stabilization nor the main landing parachute was yet qualified for its task in Project Mercury. Curiously, little research had been done on parachute behavior at extremely high altitudes. Around 70,000 feet, where the drogue chute was at first designed to open, and down to about 10,000 feet, where the main landing chute should deploy, tests had to be carried out to measure "snatch" forces, shock forces, and stability parameters. Some peculiar phenomena—called "squidding," "breathing," and "rebound" in the trade—were soon discovered about parachute behavior at high altitude and speed. In March, one bad failure of an extended-skirt cargo chute to open fully prompted a thorough review of the parachute development program. Specialists from the Air Force, Langley, McDonnell, and Radioplane, a division of the Northrop Corporation, met together in April and decided to abandon the extended-skirt chute in favor of a newly proved, yet so far highly reliable, 63-foot-diameter ringsail canopy. The size, deployment, and reliability of the drogue chute remained highly debatable while STG sought outside help to acquire other parachute test facilities.[32] The status of most other major capsule systems was still flexible enough to accommodate knowledge and experience gained through ongoing tests.

Two other major problems on which Langley also worked with STG, while NASA Headquarters planned the role and functions of the new center in Beltsville, concerned the formulation of final landing and recovery procedures and the establishment of a worldwide tracking network. Mercury planners had assumed from the beginning that the Navy could play a primary role in locating and retrieving the capsule and its occupant after touchdown. But a parallel assumption that existing military and International Geophysical Year tracking





*How to absorb the impact of landing without heavy weight penalties was a primary engineering problem. The solution: crushable aluminum honeycomb layered between the after pressure bulkhead and the heatshield (above); in the process of crushing, this material would absorb much of the shock of impact. The proof: pigs were dropped safely in a series of drop tests following the proposal in C. C. Johnson's sketch (left).*



*Parachute development and qualification was one of the areas that proved surprisingly time-consuming and troublesome, considering the long prior history of parachute use. The ring-sail parachute, shown at right in one of many test flights, was the type finally chosen to use as the capsule's main parachute.*

and communications facilities could be utilized with relatively slight modifications had to be overhauled in the light of a more thorough analysis of Mercury requirements.

The Navy's experience with search and rescue operations at sea could be trusted to apply directly without much modification to retrieval of the Mercury capsule. But a multitude of safeguards had to be incorporated in the capsule to ensure its safety during and immediately after impact and to reduce the time required for recovery to a bare minimum. William C. Muhly, STG's shop planner and scheduler, was most worried about these recovery aids for the Big Joe tests.[33]

The most serious technical decision affecting the landing and recovery procedures concerned the feasibility of using an impact bag to cushion the sudden stop at the surface of Earth. Gilruth liked the idea of using a crushable honeycomb of metal foil between the shield and the pressure vessel to act as the primary shock absorber. But a pneumatic bag, perhaps a large inner tube or a torus made of fabric and extending below the capsule, either with or without the heatshield as its base, was still appealing. Associated with the recovery problem

were innumerable other factors related to recovery operations. The seaworthiness of the capsule, its stability in a rough sea, the kinds of beacons and signaling devices to be used, and the provisions for the possibility of a dry landing were foremost among these worries.[34]

The second major area of uncertainty revealed in January 1959 came as something of a surprise to Task Group people. They had assumed that the world was fairly well covered with commercial, military, and scientific telecommunications networks that could be a basis for the Mercury tracking and communications grid. The Minitrack network established roughly north and south along the 75th meridian in the Western Hemisphere for Project Vanguard turned out to be practically inapplicable. On the other hand, the "Moonwatch" program and the optical tracking teams using Baker-Nunn cameras developed by the Smithsonian Institution Astrophysical Laboratory supplied invaluable data during 1958. Tracking of artificial satellites showed that all previous estimates of atmospheric density were on the low side.[35] Trajectory studies for equatorial orbits showed a remarkable lack of radio and cable installations along the projected track. Much depended upon the precise trajectory selections and orbital calculations for a Mercury-Atlas combination. New Atlas guidance equations that would convert the ballistic missile into an orbital launch vehicle had been assigned to the mathematicians of Space Technology Laboratories (STL) in Los Angeles. But whatever these turned out to be, it was becoming apparent that the world was far less well-wired around the middle and underside than had been thought. Furthermore the medical teams were insisting on continuous voice contact with the pilot. So by the end of February, Charles W. Mathews had convinced Abe Silverstein that STG should be relieved of the monumental tracking job, and NASA Headquarters drafted another contingent of Langley men to set up a brand-new communications girdle around the world.[36]

A large part of the Instrument Research Division at Langley, under the directorship of Hartley A. Soulé, provided the manpower. Soulé had previously laid out a timetable of 18 months for completion of a tracking network. Now he and the Langley Procurement Officer, Sherwood L. Butler, undertook to manage the design and procurement of material for its construction.[37] Ray W. Hooker accepted the supervision of the mechanical and architectural engineering, and G. Barry Graves began to direct the electronics engineering. By mid-March the problem of providing a tracking network for Mercury was on the shoulders of a special task unit that came to be known as the Tracking and Ground Instrumentation Unit, or by the barbarous acronym "TAGIU." Although by this time most of the other divisions at Langley were also acting partially in support of Mercury, the Tracking Unit held a special position in direct support of the Space Task Group. Indirectly it provided NASA with its first equatorial tracking web for all artificial satellites. Some 35 people in the unit went to work immediately on their biggest problem, described by Graves as "simply to decide what all had to be done." [38] By the end of April, Soulé had seen the imperative

*The* Rose Knot, *one of the two tracking ships used during Project Mercury, is pictured at Maryland Ship and Drydock, undergoing modifications and installation of new equipment. When completed, the ship would have a command transmitter as well as FPS–16 radar and other sophisticated tracking and electronic equipment. Below, activity in the communications support area of Goddard Space Flight Center just before a manned mission got underway. This was the relay point for all tracking network communications to and from the Mercury Control Center at Cape Canaveral.*





need for a high order of political as well as technical statesmanship to accomplish his task on time. A detailed report to Silverstein outlined his operational plans.[39]

On March 17 and 18, 1959, at the McDonnell plant in St. Louis, the manufacturers presented to the Space Task Group for its review, inspection, and approval the first full-scale mockup of the complete Project Mercury manned satellite capsule. This "Mockup Review Inspection" represented a rough dividing line between the design and development phases for the project. The "Detail Specifications," 80 pages in length, provided a program for the customers. Another McDonnell document provided a written description of the "crew station" procedures and capabilities. And the mockup itself showed the configuration "exploded" into seven component parts: adapter ring, retrorocket package, heatshield bottom, pressure bulkhead, airframe, antenna canister, and escape rocket pylon.[40]

The chief designers, constructors, and managers of the program gathered around the capsule to watch demonstrations of pilot entry, pilot mobility, accessibility of controls, pylon removal, adapter separation, and pilot escape. The board of inspection, chaired by Charles H. Zimmerman, then Chief of the Engineering and Contract Administration Division of STG, included Gilruth, Mathews, Faget, Low, Walter C. Williams, who was then still Chief of NASA's High Speed Flight Station, and E. M. Flesh, the engineering manager of Project Mercury for McDonnell. In addition, eight official advisers of the board and 16 observers from various other interested groups attended the meeting. The president of the corporation himself introduced his chief lieutenants: Logan T. MacMillan, company-wide project manager; John Yardley, chief project engineer; and Flesh. In consultation during the two days with some 40 McDonnell engineers, the Task Group recommended a total of 34 items for alteration or study. Of these recommendations 25 were approved immediately by the board, and the rest were assigned to study groups.[41]

Among the significant changes approved at this meeting were the addition of a side escape hatch, window shades, steps or reinforced surfaces to be used as steps in climbing out of the throat of the capsule, and a camera for photographing the astronaut. Robert A. Champine, a Langley test pilot who had ridden the centrifuge with Carter C. Collins and R. Flanagan Gray the previous summer to help prove the feasibility of the Faget couch concept, suggested more than 20 minor changes in instrumentation displays and the placement of switches, fuses, and other controls. Also attending this mockup review were Brigadier General Don D. Flickinger; W. Randolph Lovelace II; Gordon Vaeth, the new representative of the Advanced Research Projects Agency; John P. Stapp, the Air Force physician who had proved that man could take deceleration impacts of up to 40 g; and a relatively obscure Marine test pilot from the Navy Bureau of Aeronautics by the name of John H. Glenn, Jr.

When they returned to Langley Field, Task Group officials were aware as never before of the magnitude of their tasks. Conversations with more than 50





*The Mockup Review Inspection in St. Louis, March 17–18, 1959, was a clear-cut intricacies of climbing out of the hatch of the Mercury mockup capsule (right). Faget, one of the principal conceptual engineers from STG, briefs on the concept (left), and Gilbert North, McDonnell test pilot, is suited up and demonstrating the intracacies of climbing out of the hatch of the Mercury mockup capsule (right).*

McDonnell engineering group leaders had convinced them that more formal contract-monitoring arrangements were needed. Working committees and study groups had proliferated to such an extent that a capsule-coordination panel was needed. Gilruth appointed John H. Disher in mid-March to head the coordination temporarily. But by mid-June the panel was upgraded to an "office" and Disher was recalled to Washington by Silverstein to work with Low and Warren J. North.[42]

From a nucleus of 35 people assigned to STG in October 1958, the Group had grown to 150 by the end of January 1959. Six months later, in July, about 350 people were working in or with the Task Group, although some were still nominally attached to the research centers at Lewis or Langley.[43]

The rapid growth of STG, fully endorsed by Washington, was only one of the problems facing its management in the spring of 1959. Perhaps the most difficult lesson to learn in the first year of Project Mercury was the psychological reorientation required to meet new economic realities. Aeronautical research engineers who became administrators under NACA were still essentially group leaders of

research teams. But when NACA became NASA and embarked on several large-scale development programs, those in development, and in STG in particular, became not primarily sellers of services but rather buyers of both services and products. To manage a development program required talents different from those required to manage a research program, if only because Government procurement policies and procedures are so complex as to necessitate corps of experts in supply and logistics. Senator Stuart Symington of Missouri, one of the knowledgeable observers watching the transition at this time, remarked, "The big difference between NACA and NASA is that NASA is a contracting agency." [44]

## Costs and Cancellations

Trying to estimate what it should cost to develop hardware from their designs for a manned satellite, STG at first envisioned an expenditure of about $16 million to manufacture the program's spacecraft. But well before the contractor had been selected, Gilruth received a revised estimate based on new specifications, allowances for overtime, the fixed fee plus the estimated construction costs, and comparing capsule cost per pound with that of the X–15 and Dyna-Soar programs. George F. MacDougall, Jr., the aeronautical research scientist who signed this revised estimate, advised that the capsule costs should be raised to $22 million. Neither an economist nor a cost accountant, he did foresee the possibility "that the current estimated costs of $22,000,000 may be optimistically low." [45]

The contract negotiated with McDonnell had compromised between the company's bid of $17,583,717, which was far from the lowest, and the more liberal STG estimate, to settle on a price of $18,300,000 for manufacturing 12 capsules. In view of this compromise upward, NASA officials were unprepared for the sudden acceleration of costs that the contractor claimed was necessary for spare parts, ground support, and checkout equipment. Before the ink was dry on the prime contract, the scope of research and development work was found to have mushroomed. In March, when McDonnell advised NASA that spares and test equipment would more than double the total contract costs, Abe Silverstein applied counterpressure, saying indignantly, "I will not tolerate increases such as those above in the contract for any reasons—utterly unreasonable to increase an $18,000,000 contract to $41,000,000 by these devices." [46]

Meanwhile STG and McDonnell representatives held a meeting at the working level to consolidate and condense the requirements for spare parts and equipment. Savings effected here were eventually greatly overridden by costs arising elsewhere. No one could yet foresee that the basic contract for 12 spacecraft would have an evolutionary history of its own.[47] Cost accounting for a development program was recognized as a hazardous occupation, but just how hazardous and where to look for particular pitfalls took time to learn.

Whereas cynics might expect that the private-enterprise contractor for the capsule might have underbid to gain the contract, the civil servants in STG were

more surprised to learn that the public enterprise of furnishing the Nation's ballistic missile defense systems should also have underestimated costs by approximately one third. Informed by the Air Force Ballistic Missile Division in January that each Atlas booster would cost $3.3 million instead of $2.5 million, George Low tried for two months to get a satisfactory explanation of this sudden inflation.[48]

When in May, however, the STG learned of an increase by $8 million in the amount the Army Ballistic Missile Agency proposed to charge for the Redstones and Jupiters, the time had come for a thoroughgoing review of cost effectiveness and program requirements. Gilruth and Purser learned by investigation that the Ballistic Missile Agency was billing NASA a "burden" surcharge for the benefit of laboratory overhead costs at Huntsville. Purser's considered reaction to this was to threaten cancellation of the Jupiter program. If NASA must pay for research and development at the Redstone Arsenal, he said, then NASA, and STG in particular, must be more frugal in the estimation of their needs.

The Jupiter rocket had been selected to boost a full-scale capsule to about 16,000 feet per second, a velocity midway between the capacities of Little Joe and Redstone (6000 feet per second), and of Atlas (25,000 feet per second). But rather than insist on this step, Purser argued that the Atlas should be harnessed to duplicate the mission of the Jupiter flights. Since "the cost now equals or exceeds the cost of an Atlas for the same mission" and the Jupiter system would not be a "true duplicate of the Mercury capsule system," Purser recommended that the two Jupiter shots be canceled.[49]

After further consideration and more negotiations, Purser's recommendation was adopted by NASA Headquarters; the Jupiter series was eliminated from the Mercury program. In the aftermath of this episode, Glennan made an official complaint to the Secretary of Defense about the necessity to curtail proposed launchings to control costs, describing the situation with some chagrin:

> Members of the staff who have visited Redstone Arsenal report that exceptionally high overhead rates apparently result from the necessity of supporting a large technical staff with a limited approved work program. The net result to us has been the increased costs of a Jupiter launching to more than that of an Atlas, whereas a Redstone launching is about $200,000 less than that of an Atlas. The prices being 2.7 and 2.9 million respectively.[50]

At the same time Mercury engineers who were looking for an alternative to the balloon flight program discovered that the altitude wind tunnel, the biggest physical installation at Lewis Research Center, could be used to simulate environmental conditions up to 80,000 feet. Therefore the balloon flight test program, primarily designed to "soak" the capsule at comparable altitudes, was in effect canceled by May. DeMarquis D. Wyatt and other NASA Headquarters staffers preparing the budget requests for fiscal year 1960 now had evidence of STG's cost consciousness. The cancellations of the Jupiter series and the balloon program greatly simplified the program buildup toward manned space flight. STG engineers were pleased by the resulting concentration of effort.[51]

One reason STG shed no tears over cancellation of Jupiter and the balloon tests was that the Little Joe program was making good progress. Blueprint work for the Little Joe airframe had begun early in 1959. North American had assigned A. L. Lawbaugh as project engineer; Langley Research Center had appointed Carl A. Sandahl as its representative for support of this test booster program; and William M. Bland, Jr., was managing Little Joe for the Space Task Group. Throughout the year 1959 these three men were primarily responsible for Little Joe.

Two significant design changes for Little Joe early in 1959 undoubtedly delayed the program slightly but contributed greatly to its eventual success. The first change, decided upon by Gilruth and Faget in January, required a switch from straight to canted nozzles on all the forward-thrusting rocket motors. Little Joe had no guidance system, and such a redesign would minimize any upset from unsymmetrical thrust conditions. The other departure from the original design was the addition of a so-called "booster destruct system." In the interest of range safety there should be some provision to terminate by command the thrust of the main motor units. Therefore Charles H. McFall and Samuel Sokol of Langley devised a booster blowout system, which North American and Thiokol Chemical Corporation, the manufacturers of the rocket motor components, added to the forward end of each rocket combustion chamber.[52]

By mid-February it was apparent that a development program for rocket hardware, even of such limited scope and relative simplicity as the Little Joe booster, demanded a far more sophisticated management organization than either Langley or the Task Group had envisioned. Although informal arrangements had sufficed to get the program started, funding allocations, personnel expansion, and contract monitoring problems began to weigh heavily. Carl Sandahl lamented in one weekly progress report that the transfer of Caldwell C. Johnson from Langley to the Space Task Group could "just about break up the Little Joe Project." Langley's loss was STG's gain in this respect, however, and cooperation continued to be encouraging. Indeed, in May, Bland reported that the delivery of the first Little Joe booster airframe could be expected approximately two weeks earlier than scheduled.[53]

Parallel to the development of the Little Joe test booster, STG and Langley engineers continued work on what now was called the Scout, the multistage, solid-propellant research rocket being designed since the previous year for sounding, probe, or small satellite missions. Langley had maintained its responsibility for designing the Scout for the Air Force after NACA became NASA; and early in 1959, Robert O. Piland and Joseph G. Thibodeaux came to work with William E. Stoney on the staging principles for the long, slim rocket. Although the Scout, as a Langley project, was not an integral part of STG's activities in Project Mercury, the Task Group held open the possibility of using this simple and relatively inexpensive rocket to launch scale models of the Mercury configuration and to probe for further critical data on heat transfer and stability. Thus the

Scout's capability could fill research gaps that might arise in the manned satellite project.[54]

Since January, when it had become apparent that the Army would not soon relinquish to NASA its rocket development team at Huntsville, NASA Headquarters had encouraged the Space Task Group to proceed full speed on personnel recruitment. The exact status of the organization and authority of STG was left unspecified, while Headquarters felt its way toward the establishment of the "space projects center" at Beltsville, just outside Washington. Although NASA had a "hunting license" as a result of its enabling legislation, STG's managers could not, without full support from President Eisenhower or Administrator Glennan, know how far or how hard to push the Space Task Group toward a permanent semi-autonomous establishment.[55]

STG's need for acquiring competent people without raiding established NASA research centers was met in large degree by a fortuitous accident that dramatized Anglo-European complaints about the "brain drain" of their scientific-technological manpower to the United States. A group of over 100 Canadian and British aeronautical engineers, who had been employed on a fighter-plane project for the British A. V. Roe (AVRO) Company near Toronto, Canada, were out of work. AVRO tried to find new jobs for them when the CF–105 Arrow project was canceled as a result of the Commonwealth's decision that the Bomarc missile made the Arrow obsolescent. Twenty-five of these engineers, led by James A. Chamberlin, a Canadian, were recruited by STG and immigrated to work at NASA's Virginia colony in mid-April. They were assigned jobs as individuals with the existing teams wherever each could be most useful, and they quickly proved themselves invaluable additions to making Mercury move.[56]

At the same time, the chief business administrator of the new NASA center at Beltsville, Michael J. Vaccaro, was planning to accommodate a complement of 425 people for fiscal year 1960 should Gilruth and his manned satellite team move to Maryland. On the first day of May 1959 the "space projects center," growing out of Naval Research Laboratory's Vanguard team, was renamed the Goddard Space Flight Center, and Gilruth's second hat, as the Center's Assistant Director for Manned Satellites, was reaffirmed. The Mercury program was specified as one of the six divisional offices at Goddard.[57]

While many questions of personnel, network management, and contract procedures for the capsule were still pending, Glennan made his first visit to the Space Task Group at Langley on May 18, 1959. He was impressed by the enormity of Project Mercury, by its working-level complexities, and by the extraordinarily fine morale in STG. Glennan returned to Washington resolved not to tamper with the esprit of STG. But he was also determined that NASA as a whole should not become a "space cadet" organization.[58] The Administrator's resolution that NASA must not be overwhelmed by the complexities of manned space flight led to a Headquarters policy of minimal interference with the Task Group. During the next year, however, the weight of pressure from



*NASA Administrator T. Keith Glennan, right, arrives at Langley Field for his first visit to the Space Task Group. He is greeted by Robert R. Gilruth, left, Director of Space Task Group, and Floyd L. Thompson, Director of Langley Research Center.*

the public press and the scope of intragovernmental coordination related to Mercury was to strain this policy.

## Supporting Agencies and Industries

One of these complexities had been pointed up in the course of planning operational procedures for launching. Back in November 1958 the Air Force Missile Test Center had accepted Melvin N. Gough as director of NASA tests, but it was May 1959 before the Center made any allowance for the functioning of NASA's skeleton staff for the manned satellite program. When Herbert F. York, the Pentagon's Director of Defense Research and Engineering, testified before Congress early in June, he alluded to the coordination problem between the Department of Defense and NASA and admitted, "We haven't worked out exactly how to do that yet." B. Porter Brown, the first STG man to take up residence at the Cape, told his superior, Charles Mathews, that the administration of the launch complexes at the Atlantic Missile Range was as intricate as the technical equipment there.[59]

On May 1, 1959, when NASA set up its own liaison office at Canaveral, Brown and the STG were still trying to understand all the interrelationships

existing between the Air Force (whose proprietorship stemmed from the establishment in 1950 of the Long Range Proving Ground), the Navy, and the Army. The Air Force Missile Test Center (AFMTC) was the steward operating the Atlantic Missile Range (AMR) for the Department of Defense. The Army had established its subsidiary Missile Firing Laboratory on the Cape as an integral part of its Ballistic Missile Agency. By the end of January 1959, Kurt H. Debus, director of the firing lab, had appointed a project engineer and coordinator for the Mercury-Redstone program, but the conversion of launch pads Nos. 5 and 6 into "Launch Complex No. 56" to meet the requirements for Mercury-Redstone launchings was less imperative than the need to prepare for the Fourth of July launch of Mercury's Big Joe by an Air Force Atlas.[60]

The palmetto-covered dunes at Canaveral had several dozen different kinds of launch pads, but they were still in short supply and under heavy demands. There were almost as many different military service and civilian contract organizations vying for them as there were pads. Proprietary interests were strongly vested, security restrictions were rigorous, and the newly constituted space agency was not yet accepted in the elite flight operations society there. Hangar S, in the industrial area of the Cape, had been tentatively assigned as "NASA space," but the former Naval Research Laboratory team that had built Hangar S and was still active with the Vanguard project was there first. Although now incorporated with NASA, the Vanguard team hoped to carry on with a new booster development program named Vega. Another group of half-NASA developers, the Jet Propulsion Laboratory, working with von Braun's people, were likewise seeking more room to convert Juno I (Jupiter-C) into Juno II (Jupiter IRBM) launch facilities for more Explorer satellite missions.[61]

With space for space (as opposed to defense) activities at such a premium, Porter Brown and his two advance-guard colleagues for STG at the Cape, Philip R. Maloney and Elmer H. Buller, pressed for a higher priority in Hangar S. But room was still scarce in early June when Scott H. Simpkinson with about 35 of his test operations engineers from Lewis Research Center arrived to set up a preflight checkout laboratory for Big Joe. They found a corner fourth of Hangar S roped off for their use, and instructions not to overstep these bounds.[62]

Another problem arose over the scheduled allocation of launch pad No. 14, which was one of only five available for Atlas launchings. Pad 14 was scheduled to be used for the Air Force MIDAS (Missile Defense Alarm Satellite) launchings throughout the same time period that the Mercury qualification flights were expected to be ready. Although admitting that firing schedules for both the Mercury-Redstone and the Mercury-Atlas programs were tentative, STG argued that the same pad assigned for the Big Joe shot should be continuously available for preparing all subsequent Mercury-Atlas launches.

The commander of the Air Force Missile Test Center disagreed. In the cause of maximum utilization of Cape facilities, Major General Donald N. Yates ordered switching of Mercury launches to various available launch stands. These initial

conflicts of interests reached an impasse on June 24, when representatives of NASA and the Advanced Research Projects Agency of the Department of Defense met to decide whose shots to postpone. NASA was unable to obtain a concession: the urgency of ICBM and MIDAS development took precedence.[63]

The complexity of organizational problems at the Cape might have led space agency leaders to despair but for an auspicious space flight on May 28. On that date in 1959 an Army Jupiter intermediate range ballistic missile launched a nose cone carrying two primate passengers—Able, an American-born rhesus monkey, and Baker, a South American squirrel monkey—to a 300-mile altitude. At the end of 15 minutes and a 1500-mile trajectory, along which the cone reached a speed of about 10,000 miles an hour, the Navy recovered Able and Baker alive and healthy. The medical experiments were conducted by the Army Medical Service and the Army Ballistic Missile Agency with the cooperation of the Navy and Air Force Schools of Aviation Medicine. Not only was the flight a triumph for space medicine; it also demonstrated an organizational symbiosis of significant proportions for all of the services and branches involved.[64]

But the "interface" problems within NASA, and between NASA and other agencies, continued to exist, particularly at lower echelons in the planning of operational procedures for flight control. Mathews and his staff in the Flight Operations Division of STG were required to plan and replan mission profiles, schedules, countdown procedures, and mission directives while accommodating the procedures of other divisions and organizations contributing to the operation. By mid-spring these working relationships had become so involved that flight schedules had to undergo radical revision. It gradually became clear that the original schedules aimed at achieving a manned orbital flight early in April 1960 could not possibly be met.

On top of that, the production of spacecraft hardware and flight equipment began falling behind schedule. Only one month after the Mockup Review, it became evident that capsule and systems production slippages were going to become endemic. On April 17, 1959, Gilruth, speaking before the World Congress of Flight meeting at Las Vegas, announced casually, "The first manned orbital flight will not take place within the next two years." The first successful pad abort using the tower-rocket escape system had just been completed on April 12—two years to the day before Gagarin's orbital flight—but Gilruth cautiously refrained from pronouncing even the escape sequence firm. And he alluded to other areas of uncertainty:

> Although the Mercury concept is the simplest possible approach to manned flight in space, involving a minimum of new developments, as you can see, a great deal of research and development remains to be done. For flight within the atmosphere, the capsule must be stable over the widest speed range yet encountered by any vehicle—from satellite velocity to a very low impact speed. And in orbital flight, all of the systems must function properly in a weightless state. It must be compatible with the launch rocket and must be at home on the sea while awaiting recovery.[65]

## FROM DESIGN INTO DEVELOPMENT

In May 1959 the Mercury managers drew up a new functional organization chart dividing the supervisory activities of STG into five categories: capsules, boosters and launch, "R and D" support, range, and recovery operations. The design period for each of these areas having now evolved into developmental work, each area could more plainly be seen in terms of the contracts to be monitored by STG personnel. Capsules were divided into three categories, the first of which was the boilerplate models being built by Langley for the Little Joe program. For Big Joe, alias the Atlas ablation test, another boilerplate capsule was under construction jointly, with the STG at Langley responsible for the upper section and the STG at Lewis for the lower pressure-vessel section of the capsule. This meant that Langley in conjunction with Radioplane would perfect the recovery gear and parachute canister, while Lewis people would handle the automatic control system, the heatshield, sensors, and telemetry.[66]

For the production model capsule under McDonnell's aegis, a number of major subcontractors had long since been selected. Minneapolis-Honeywell Regulator Company was developing the automatic stabilization and control system; the reaction control system was being built by Bell Aerospace Corporation; some electronics and most radio gear were to be provided by Collins Radio Company; and the environmental control system, the periscope, and the horizon scanner were to be supplied by AiResearch, Perkin-Elmer Company, and Barnes Instrument Company, respectively. The alternative heatshields, as previously noted, were being provided by several different subcontractors; and the solid rockets for escape by Grand Central Rocket Company and for the retrothrust package by Thiokol Chemical Corporation.

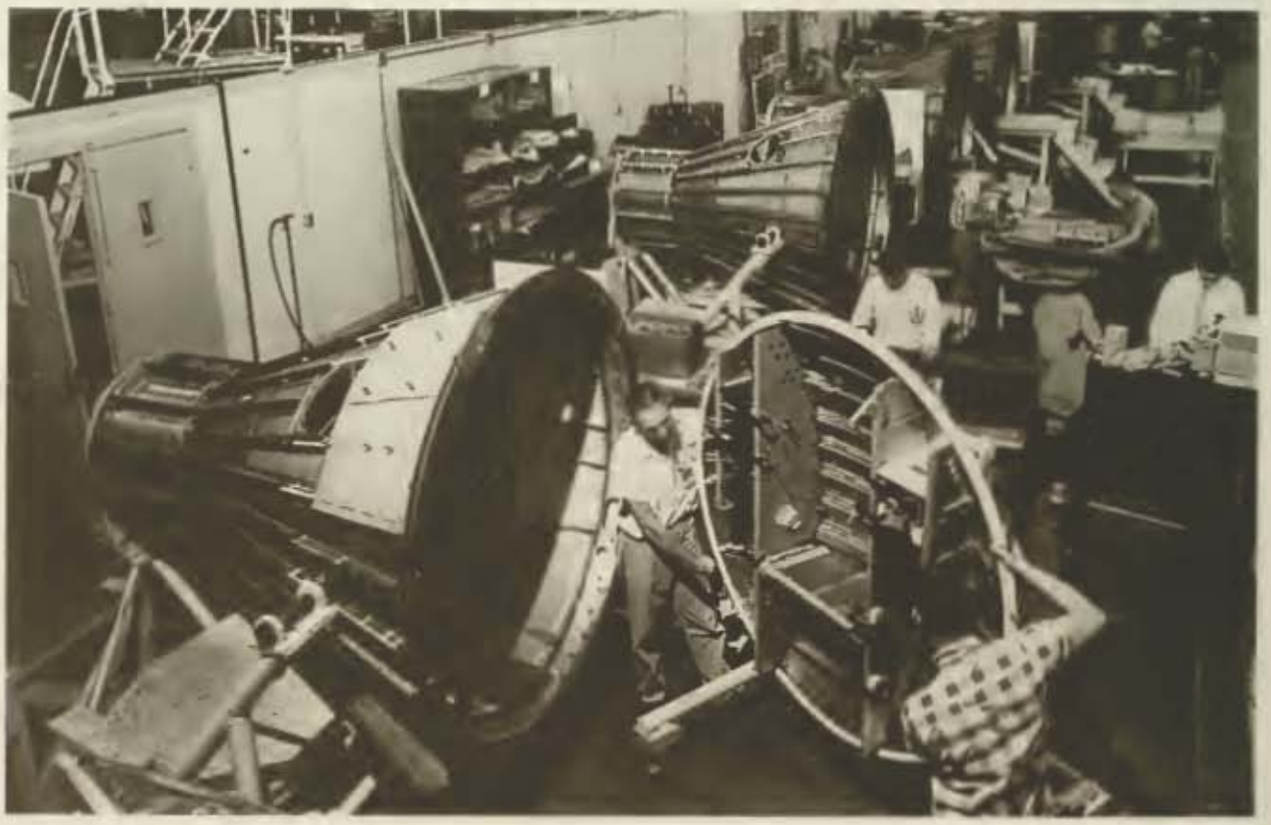
With regard to boosters and launching, STG could rely on the extensive experience of the Ballistic Missile Division/Space Technology Laboratory/Convair complex for the Atlas, and on the Army Ballistic Missile Agency and the von Braun/Debus team for the Redstones. Only the Little Joe shots from Wallops Island would require extensive attention to launch problems because only Little Joe was exclusively a NASA booster. North American, the prime contractor, would provide whatever Langley could not for Little Joe.

Under the miscellaneous category "R and D support," however, Project Mercury would not only require the help of all the other NASA research centers—Langley, Ames, Lewis, and now Goddard—but also of the NASA stations for high-speed flight research at Edwards, California, and for pilotless aircraft research at Wallops Island, Virginia. At least 10 separate commands under the Air Force would be closely involved, and various facilities of the Navy Bureau of Aeronautics, especially the human centrifuge at Johnsville, Pennsylvania, would likewise be extensively used.

The range and tracking network requirements being supervised by the alter ego to STG, namely the Tracking Unit (TAGIU) or the Mercury network group at Langley, gradually became clear as contractors began to report on their feasibility and programming studies. The Lincoln Laboratory of the Massachusetts



*The two major systems of Mercury flight hardware were of course the launch vehicle—the man-rated Atlas—being produced at General Dynamics/Astronautics plant in San Diego (left) and the Mercury spacecraft, being assembled at the McDonnell Aircraft Corporation plant in St. Louis (below).*



Institute of Technology, the Aeronutronics Division of the Ford Motor Company, Space Electronics Corporation, and the RCA Service Company held four study contracts to help Soulé decide on ground equipment, radar coverage, control center arrangements, and the exact specifications for various contracts. Although a preliminary bidders' briefing on the tracking, telemetry, and telecommunications plans for Project Mercury took place at Langley on April 1, the basic design document, "Specifications for Tracking and Ground Instrumentation System for Project Mercury," did not appear until May 21. Consequently NASA did not select the prime contractor for the tracking network until midsummer.[67]

Finally, regarding recovery operations, a NASA and Department of Defense working group decided on May 11 to make use of the investment already made by Grumman Aircraft Corporation in operations research for its spacecraft bid proposal on recovery requirements. Concurrently arrangements were being made with the Chief of Naval Operations, the Commander in Chief of the Atlantic Fleet, the Army Ballistic Missile Agency, the Strategic Air Command, the Atlantic Missile Range, the Marines, and the Coast Guard for the specific help each could render when the time should come for search and retrieval.

Although these relations appeared to have grown exceedingly complex, they had only just begun to multiply. Gilruth, however, was confident that by careful coordination and through the largely personal and informal working methods of STG, he and his men could handle the problems arising in the Mercury development program. As an encouraging example, the booster and launch coordination panels, established separately for the Atlas and the Redstone, had by mid-May already achieved impressive understandings on what had to be done. In the case of the Atlas, the coordination panel worked out the division of labor between NASA, McDonnell, the Ballistic Missile Division, Convair, and STG. Panel members simply discussed until they had resolved such key problems on their agenda as general launch operations procedures, trajectories and flight plans for the first two scheduled launches, general approach to an abort sensing system and procedures, range and pad safety procedures, general mechanical and electrical mating, blockhouse space requirements, general countdown and checkout procedures, and velocity cutoff in the event of overshooting the orbit insertion point. Six Redstone booster and launch panels, established at an important coordination meeting on February 11 with STG and McDonnell at Redstone Arsenal, likewise resolved in monthly meetings many such items.[68] For both boosters, many details remained outstanding, of course, but the fact that pending problems were being identified early and systematically in May 1959 gave the STG confidence that no further schedule slippages could be charged to the lack of intelligent planning.[69]

### Astronaut Selection

Now that the men had been chosen to serve as the focal points for all this effort, new spirits animated the Space Task Group. Indeed, the Nation as a whole

began to participate vicariously in Project Mercury when, on April 9, 1959, at a press conference in Washington, Glennan introduced to the public the seven men chosen to be this Nation's nominees for the first human voyagers into space.[70]

They were to be called "astronauts," as the pioneers of ballooning had been called "aeronauts," and the legendary Greeks in search of the Golden Fleece were called "Argonauts," for they were to sail into a new, uncharted ocean. These personable pilots were introduced in civilian dress; many people in their audience forgot that they were volunteer test subjects and military officers. Their public comments did not class them with any elite intelligentsia. Rather they were a contingent of mature Americans, average in build and visage, family men all, college-educated as engineers, possessing excellent health, and professionally committed to flying advanced aircraft.

Compared with the average, white, middle-class American male, they enjoyed better health, both physically and psychologically, and they had far more experience among and above the clouds. Slightly short of average in stature, they were above average in seriousness of purpose. Otherwise these seven seemed almost random samples of average American manhood. Yet the names of Carpenter, Cooper, Glenn, Grissom, Schirra, Shepard, and Slayton were perhaps to become as familiar in American history as those of any actor, soldier, or athlete.

Despite the wishes of NASA Headquarters, and particularly of Dryden, Silverstein, and Gilruth, the fame of the astronauts quickly grew beyond all proportion to their current activities and their preflight mission assignments. Perhaps it was inevitable that the "crew-pool" members of STG were destined for premature adulation, what with the enormous public curiosity about them, the risk they would take in space flight, and their exotic training activities. But the power of commercial competition for publicity and the pressure for political prestige in the space race also whetted an insatiable public appetite for this new kind of celebrity. Walter T. Bonney, long a public information officer for NACA and now Glennan's adviser on these matters, foresaw the public and press attention, asked for an enlarged staff, and laid the guidelines for public affairs policy in close accord with that of other Government agencies.[71]

The astronauts were first and foremost test pilots, men accustomed to flying alone in the newest, most advanced, and most powerful vehicles this civilization had produced. They were talented specialists who loved to fly high-performance aircraft and who had survived the natural selection process in their profession. The demand for excellence in piloting skills, in physical health, and psychological adaptability becomes ever more stringent as one ascends the ladder toward the elite among military aviators, those senior test pilots with upwards of 1500 hours' total flying time.[72]

Eisenhower's decision that the military services could provide the pilots greatly simplified the astronaut selection procedure. From a total of 508 service records screened in January 1959 by Stanley C. White, Robert B. Voas, and William S. Augerson at the military personnel bureaus in Washington, 110 men were found to

meet the minimum standards specified earlier. This list of names included five Marines, 47 Navy men, and 58 Air Force pilots. Several Army pilots' records had been screened earlier, but none was a graduate of a test pilot school. The selection process began while the possibility of manned Redstone flights late in 1959 still existed on paper.[73]

The evaluation committee at Headquarters, headed by the Assistant Director of STG, Charles J. Donlan, decided to divide the list of 110 arbitrarily into three groups and to issue invitations for the first group of 35 to come to Washington at the beginning of February for briefings and interviews. Donlan was pleased to learn from his staff, White, Voas, and Augerson, that 24 of the first group interviewed were happy with the prospects of participating in the Mercury program. Every one of the first 10 men interrogated on February 2 agreed to continue through the elimination process. The next week another group of possible pilot-candidates arrived in Washington. The high rate of volunteering made it unnecessary to extend the invitations to the third group. Justifying this action, George Low reported:

> During the briefings and interviews it became apparent that the final number of pilots should be smaller than the twelve originally planned for. The high rate of interest in the project indicates that few, if any, of the men will drop out during the training program. It would, therefore, not be fair to the men to carry along some who would not be able to participate in the flight program. Consequently, a recommendation has been made to name only six finalists.[74]

Sixty-nine men had reported to Washington in two groups by the middle of February. Of these, six were found to have grown too tall. Fifty-six test pilots took the initial battery of written tests, technical interviews, psychiatric interviews, and medical history reviews. Those who declined or were eliminated reduced the total at the beginning of March to 36 men. They were invited to undergo the extraordinary physical examinations planned for them at the Lovelace Clinic in Albuquerque. Thirty-two accepted and became candidates, knowing also that they were scheduled to pass through extreme mental and physical environmental tests at the Wright Air Development Center, in Dayton, Ohio, after being certified as physically qualified by the Lovelace Clinic. The 32 candidates were assured that the data derived from these special examinations in New Mexico and Ohio would not jeopardize their military careers, since none of the findings was to go into their service records.

Although the psychophysiological criteria for the selection of the best possible pilots for manned space flight had been under discussion for several years, the actual arrangement of the selection procedures for Mercury was directed by a NASA selection committee consisting of a senior management engineer, Donlan; a test pilot engineer, North; two flight surgeons, White and Augerson; two psychologists, Allen O. Gamble and Voas; and two psychiatrists, George E. Ruff and Edwin Z. Levy. These seven men had done the screening of records and the interviews and testing in Washington, constituting phases one and two of the

selection program, before remanding their pool of 32 candidates to the medical examiners at the Lovelace Foundation.[75]

Individually each candidate arrived at Albuquerque to undergo approximately a week of medical evaluations under each of five different schedules. In this third phase of the program, over 30 different laboratory tests collected chemical, encephalographic, and cardiographic data. X-ray examinations thoroughly mapped each man's body. The ophthalmology section and the otolaryngology sections likewise learned almost everything about each candidate's eyes, and his ears, nose, and throat. Special physiological examinations included bicycle ergometer tests, a total-body radiation count, total-body water determination, and the specific gravity of the whole body. Heart specialists made complete cardiological examinations, and other clinicians worked out more complete medical histories on these men than probably had ever before been attempted on human beings. Nevertheless the selectees were so healthy that only one of the 32 was found to have a medical problem potentially serious enough to eliminate him from the subsequent tests at the Wright Aeromedical Laboratory.[76]

Phase four of the selection program was an amazingly elaborate set of environmental studies, physical endurance tests, anthropometric measurements, and psychiatric studies conducted at the Aeromedical Laboratory of the Wright Air Development Center. During March each of the 31 subjects spent another week experiencing a wide range of stressful conditions. Voas explained phases three and four: "While the purpose of the medical examinations at Lovelace Clinic had been to determine the general health status of the candidates, the purpose of the testing program at Wright Field was to determine the physical and psychological capability of the individual to respond effectively and appropriately to the various types of stresses associated with space missions." [77] In addition to pressure suit tests, acceleration tests, vibration tests, heat tests, and loud noise tests, each candidate had to prove his physical endurance on treadmills, tilt tables, with his feet in ice water, and by blowing up balloons until exhausted. Continuous psychiatric interviews, the necessity of living with two psychologists throughout the week, an extensive self-examination through a battery of 13 psychological tests for personality and motivation, and another dozen different tests on intellectual functions and special aptitudes—these were all part of the week of truth at Dayton.[78]

Two of the more interesting personality and motivation studies seemed like parlor games at first, until it became evident how profound an exercise in Socratic introspection was implied by conscientious answers to the test questions "Who am I?" and "Whom would you assign to the mission if you could not go yourself?" In the first case, by requiring the subject to write down 20 definitional identifications of himself, ranked in order of significance, and interpreted projectively, the psychologists elicited information on identity and perception of social roles. In the peer ratings, each candidate was asked which of the other members of the group of five accompanying him through this phase of the program he liked best,

which one he would like to accompany him on a two-man mission, and whom he would substitute for himself. Candidates who had proceeded this far in the selection process all agreed with one who complained, "Nothing is sacred any more." [79]

Back at STG headquarters at Langley, late in March 1959, phase five began. The final evaluation of data was made by correlating clinical and statistical information from New Mexico and Ohio. Eighteen of the 31 candidates came recommended without medical reservations for final consideration by Donlan and North. According to Donlan, although the physicians, psychiatrists, psychologists, and physiologists had done their best to establish gradations, the attrition rate was too low. So the final criteria for selecting the candidates reverted to the technical qualifications of the men and the technical requirements of the program, as judged by Donlan, North, White, and finally Gilruth. "We looked for real men and valuable experience," said Donlan. The selection tests, as it turned out, were largely tests of tests, "conducted as much for the research value in trying to formulate the characteristics of astronauts as for determining any deficiencies of the group being examined." The verbal responses at the interviews, before and after the psychophysiological testing, therefore, seem to have been as important final determinants as the candidates' test scores.[80]

Sitting in judgment over 18 finalists, Donlan, White, and North pared down the final pool of selectees, choosing each to complement the rest of the group. The going was so difficult that they could not reach the magic number six, so Gilruth decided to recommend seven. Donlan then telephoned each of the seven individually to ask whether he was still willing to accept a position as a Mercury astronaut. Each one gladly volunteered again. The 24 who were passed over were notified and asked to reapply for reconsideration in some future program. Gilruth's endorsement of the final list was passed upward to Silverstein and Glennan for final review, and by mid-April the faces of America's original seven spacemen were shown to the world.

As the astronauts lost their private lives, Project Mercury found its first great public notice. An eighth military officer and pilot came aboard STG about the same time to manage the public information and press relations that were already threatening to intrude on the time and talent of STG. The eighth personality was an experienced Air Force pilot who had flown extensively in World War II, on the Berlin Airlift, and in Korea, and who also had proven himself as a public information officer after 1954, when he was charged with ameliorating public fears and complaints over jet noises, sonic booms, and the ballistic missile programs.[81] Lieutenant Colonel John A. Powers, USAF, came on board the STG staff in early April 1959. Thereafter the mellifluous voice and impish grin of "Shorty" Powers made his reputation as the primary buffer for STG in its relations with the press and the public. Throughout the Mercury program, he stood before the news media and the people of the world as the one living symbol of all the anonymous human effort behind the astronaut of the moment.

Powers propagated some oversimplified images in many instances, as it was

his job to do, but no one man then or now could completely understand or communicate the complexity of the myriad research, development, and operations activities that lay behind a launch. Then, too, the caliber of the questions determined the quality of his answers, and all too often the questions asked were simple. What was an astronaut really like? What did he eat for breakfast? Which ones had been Boy Scouts? How did their wives take their commitment? Such questions provoked many to abandon asking how these seven came to be chosen and for what purpose they were entering training.

From the United States Marine Corps, Lieutenant Colonel John Herschel Glenn, Jr., received orders to report to the Space Task Group at Langley Field, on the first of May. He then found himself the senior astropilot in age and date of rank. From the Navy, Walter Marty Schirra, Jr., and Alan Bartlett Shepard, Jr., both lieutenant commanders, and Lieutenant Malcolm Scott Carpenter reported aboard STG. And the Air Force assigned three captains, Donald Kent Slayton, Leroy Gordon Cooper, Jr., and Virgil I. Grissom, to duty with NASA as test pilots, alias Mercury astronauts.

On May 28, 1959, the astronauts were brought before the House Committee on Science and Astronautics in executive session. They were asked to reassure the Congressmen that they were content with the orderliness, safety, and seriousness of Project Mercury. This they did vigorously, together and separately, before Schirra mentioned the "seven-sided coin" of competition over which one should get the first flight.[82]

The first seven American astronauts were an admirable group of individuals chosen to sit at the apex of a pyramid of human effort. In training to transcend

*Project Mercury astronauts pose for an informal group portrait: From left to right, John H. Glenn, Jr.; Donald K. Slayton; M. Scott Carpenter, Jr.; Virgil I. Grissom; Walter M. Schirra, Jr.; Alan B. Shepard, Jr.; and L. Gordon Cooper, Jr.*



gravity they became a team of personalities as well as a crew of pilots. They were lionized by laymen and adored by youth as heroes before their courage was truly tested. In volunteering to entrust their lives to Mercury's spirit and Atlas' strength to blaze a trail for man into the empyrean, they chose to lead by following the opportunity that chance, circumstance, technology, and history had prepared for them. Influential 20th-century philosophers as diverse as Bertrand Russell, Teilhard de Chardin, and Walter Kaufmann tell us that man's profoundest aspiration is to know himself and his universe and that life's deepest passion is a desire to become godlike. All men must balance their hubris with their humility, but, as one of those aspiring astronauts said, "How could anyone turn down a chance to be a part of something like this?" [83]

Shortly after the astronauts were introduced to the public, a literate layman asked directions of Mercury for mankind in general:

> Which way will heaven be then?
> Up?
> Down?
> Across?
> Or far within? [84]

# VII

## Man-Rating the Machines

(JULY–DECEMBER 1959)

SADDLING ballistic missiles for manned space flight was in some respects like trying to ride Sinbad's roc: the bird was not built for a topside burden, and man was not meant for that sort of punishment. Once accepted in theory that this fabulous bird could be domesticated and that some men could tolerate, even enjoy, the strains and stresses of such a ride, practical questions of marrying the separate abilities of man and machine demanded immediate answers. Engineers in the Space Task Group and other NASA researchers at Langley, Lewis, and Ames were providing some of these answers; engineers and technicians in industry and in quasi-military organizations contributed equally important answers. The primary task of the Task Group managing Mercury was to ask the right questions and to insist on better answers from the industrial producers of the parts and from the academic, industrial, and military suppliers of services.

In the latter half of 1959, as STG monitored the gathering momentum of the various manufacturers, the urgent search for ways to reduce the ultimate risk of sending a man for a ride in an artificial moon lifted by a missile gradually became more systematic and better organized. The theme of this chapter is the quest for reliability in the automatic machinery developed for the Mercury mission. Making these devices safe enough for man took longer and exposed more doubts than STG had expected originally. During the curiously quiet first half of 1960, the flexibility of the Mercury astronaut complemented and speeded the symbiosis of man and missile, of astronaut and capsule. Technology, or hardware, and techniques, or procedures—sometimes called "software" by hardware engineers—both had to be developed. But because they were equally novel, reliability had to be built into the new tools before dexterity could be acquired in their use.[1]

At the beginning of 1959 NASA Headquarters had worried about three scientific unknowns needing resolution before actual attempts to conduct manned

orbital flights. In their contribution to a House Committee Staff Report prognosticating for Congress on *The Next Ten Years in Space, 1959–1969,* Administrator T. Keith Glennan and the chief scientists at the helm of NASA in Washington listed these imperatives that must be investigated before man could go into space:

> The problems known to exist include (1) high-energy radiation, both primary and cosmic ray and the newer plasma type discovered in the IGY satellite series; (2) man's ability to withstand long periods of loneliness and strain while subjected to the strange environment of which weightlessness is the factor least evaluated; and (3) reentry into the atmosphere and safe landing. The reliability of the launching rocket must be increased before a manned capsule is used as a payload. Once these basic questions have been answered, then we can place a manned vehicle in orbit about the earth.[2]

By July 1959 the engineers in the Space Task Group were no longer concerned by the unknowns in each of these problematic areas. They had obviated the need for high-energy radiation shielding by selecting a circular orbit around the equatorial zone at an altitude between 80 and 120 miles, well above the stratosphere and well below the Van Allen belts. Loneliness would be no problem because the communications network would keep the astronaut in almost constant voice contact with ground crews. Weightlessness, to be sure, was the factor least evaluated, but by now this was the prime scientific variable that Project Mercury was designed to answer. The psychological outlook was good anyway, argued STG rhetorically, for does not everyone who has learned to swim enjoy the freedom and relatively "weightless" state when immersed in water? As to reentry, the strain of positive and negative acceleration forces had almost certainly been conquered; only a few questions remained unanswered about actual reentry and recovery stresses. Indeed, what Headquarters had left unnumbered in its presentation and therefore seemed to have regarded almost as an afterthought, the Task Group considered the paramount problem: the reliability of the rocket boosters must be increased before manned capsules could be attached to them.

The first major proof test of a critical part of the Mercury spacecraft design occurred on April 12, 1959. After a dismal failure a month before, the escape-tower rocket attached to a full-scale boilerplate model demonstrated its ability to lift both man and capsule away from a dangerous booster still on the ground. Giving first priority to providing an escape system in case of failure at launch was evidence of a pervading lack of confidence in the reliability of the big rockets. The men of the Space Task Group were not liquid-fuel propulsion experts; they had to rely on missile technicians and managers to convert weapon systems into launch vehicles for spacecraft. Since no one was expert in spacecraft engineering, STG had to rely on itself and on McDonnell Aircraft Corporation to gain as much experience as rapidly as possible with the capsule and its systems. This high adventure of learning how, specifically, to orbit a man safely was shared by a growing number of people supporting Project Mercury.

## Mercury Team Takes Shape

Although Robert R. Gilruth's Space Task Group was growing rapidly, it remained small enough and intimate enough throughout 1959 to make everyone feel his worth. The creative engineering challenge of the project inspired an esprit that could be measured by the amount of voluntary overtime and vacation time relinquished by the members of STG. Gilruth's administrative assistant for staff services, 46-year-old Paul D. Taylor, died of a heart attack in May and was mourned by his colleagues as a martyr who overworked himself in the cause.[3]

According to its own estimates of present and future manpower requirements, the Task Group was hard pressed to meet all its commitments in mid-1959. At the beginning of the new fiscal year on July 1, NASA authorized the Task Group to hire another 100 persons, mostly recent college graduates. A total of 488 authorized positions was to be filled by the end of the calendar year. But STG argued that only one of its three major divisions at work on Mercury—Operations, under Charles W. Mathews—was fairly equal in numbers to the tasks at hand so far. The Flight Systems Division, under Maxime A. Faget, was called "greatly understaffed," and the Engineering and Contract Administration Division, now under the acting leadership of the Canadian James A. Chamberlin, was in "such urgent need" of more technical and administrative help that the Space Task Group requested 200 additional positions, to be filled within the next three months. Estimates of increased Langley and Lewis support activities for Project Mercury almost doubled this personnel request. The sheer size and immense scope of industrial and military personnel required to support Mercury stirred STG to a premonition of precarious control:

> In summary, a detailed study of staffing requirements for Project Mercury shows that the presently authorized complement of 388 should be increased by 330 positions during fiscal year 1960 in order to maintain the project schedules. This staff of 718 should be available by September of 1959, but orderly recruitment and integration of the additional staff would defer the filling of the complement until April of 1960. It is believed that everything practicable in the line of contracting on Project Mercury has been done without going to the extreme of effectively relinquishing control of the project. Failure to obtain the additional personnel shown must result in either major slippage of the schedule or in NASA effectively losing control of the project to the military or to industry.[4]

Because there was still no official commitment to manned space flight programs beyond Mercury and because hope was still high that manned orbital flight could be accomplished by the end of 1960, the Task Group accepted its temporary status and planned to phase out the people working on Project Mercury beginning in June 1961. Such plans were tentative, of course, and did not reckon with the technical and organizational problems that were to stretch out the program, nor with the astronautical and political events that were to change the course and expand the role of NASA's manned space flight efforts in 1961.

Nevertheless, by early August 1959, Gilruth was able to put his own field element of the Goddard Space Flight Center in much better order through a major reorganization.[5] His new title, Director of Project Mercury, was indicative of the expanded size and activity of the Task Group. The functions of "project manager" for engineering administration devolved upon Chamberlin, who also headed the new Capsule Coordination Committee. Addition of staff services and elaboration of branch and section working group leaders after August 3 made STG's organization charts much more detailed. But the block diagrams, while helpful to new recruits and to industrial visitors at the crowded old brick administration building at the eastern entrance to Langley Field, showed rather artificial separations of activity and authority within STG. The intimacy of the original group had suffered inevitable attrition as the result of an eightfold increase in size in less than a year, but the "inner circle" still operated personally rather than formally. Outside relationships, even those with Langley Research Center, on the other side of the airbase, were rapidly demanding more formality.

A partial solution to these problems, which in time grew to be one of the most important organizational decisions ever made for Project Mercury, was the informal agreement made in August 1959 between the Defense Department and NASA to select two men to act as "single points-of-contact." DOD appointed Major General Donald N. Yates, Commander of the Air Force Missile Test Center, to become in October its representative for military support activities for Project Mercury. The job of mobilizing and coordinating such diverse activities as Air Force prelaunch and launch support, Navy search and recovery operations, Army tracking and communications facilities, and joint service and bioastronautics resources demanded systematic, formal organization.[6] In turn, Hugh L. Dryden for NASA asked the chief of the High Speed Flight Station, Walter C. Williams, to join Gilruth to act as the contact point with Yates. Effective September 1, 1959, Williams and his colleagues Kenneth S. Kleinknecht and Martin A. Byrnes accepted transfers from NASA's High Speed Flight Station—shortly to be renamed the NASA Flight Research Center—to the Space Task Group. Having pioneered since 1945 in airborne launches of rocket research aircraft, Williams was a senior convert to the vertical ground launch cause of Mercury. Faget especially welcomed him. A personable and forceful leader, Williams took a position on a level with Charles J. Donlan. Each was an associate director for Project Mercury, Williams specializing in operations and Donlan in development. Williams had guided the NACA–NASA role in the flight operations of the X–15 rocket plane to a point just two days short of its first powered flight, on September 17, with North American Aviation's test pilot A. Scott Crossfield at the controls. When Williams, Kleinknecht, and Byrnes took up the higher national priority and professional challenge of working with spacecraft rather than aircraft, they brought to STG valuable operational and development experience with the highest-performance manned flight vehicles then in existence.[7]

Although there was pressure to get on with operations planning, engineering the Mercury capsule was still the primary task during these days. McDonnell and STG had swapped permanent field representatives during the spring in the persons of Frank G. Morgan and Wilbur H. Gray. Morgan came to live in a motel at Langley. Gray found a residence in St. Louis near the north side of Lambert Field, where the McDonnell plant was spread around the perimeter of the municipal airport. Though their technical liaison work was heavy, Morgan and Gray acted as hosts and guides as much as consultants, because visits by exchange delegations of engineers were so frequent. Just as the coordination of these meetings and trips for the development of the capsule became imperative among the aircraft and spacecraft designers and developers, so were closer, more orderly relations required with the developers of the ballistic missile boosters. Aerospace engineers often used one word to express the adaptation of systems, modules, organizations, and even technologies to one another: that word was "interface"; it connoted problems of integration, convergence, and synthesis of indeterminate magnitude.

## Converging Technologies

The problem of man-rating the Redstone rocket was tackled with characteristic gusto by Joachim P. Kuettner, the man Wernher von Braun had called in 1958 to lead the Army's effort if Project Adam had been authorized. Kuettner had earned doctorates in law, physics, and meteorology before he became a flight engineer and test pilot for Messerschmitt during the Third Reich. Having been one of the first to test a manned version of the V–1 in 1944, Kuettner had made further use of his avocation as a jet aircraft and sailplane pilot for the U.S. Air Force Cambridge Research Center before joining the Army Ballistic Missile Agency (ABMA) at Huntsville.

In retrospect Kuettner has generalized about the problem of "Man-Rating Space Carrier Vehicles" in terms relating his experience with both aviation and missile technologies:

> While it is admittedly an oversimplification, the difference between the two technologies may be stated in the following general terms. From an aviation standpoint, man is not only the subject of transportation, and as such in need of protection as a passenger; but he is also a most important integral part of the machine over which he truly has control. His decisions in expected and unexpected situations are probably the greatest contributions to his own safety. Aviation, to the best of our knowledge, has never seen the necessity for a fully automatic initiation of emergency escape.
>
> In contrast, rocket technology has been for 20 years a missile technology governed by the requirements of target accuracy and maximum range. As such, it had to develop automatic controls. Unlike a human payload, a warhead has no use except on the target. Once the missile fails, it may as well destroy itself during flight. (For this reason, missilery has accepted aerodynamically unstable vehicles which, in case of loss of thrust, flip over and break apart,

destroying themselves in the air.) There has been no need to save the payload after a successful flight or in case of a catastrophe.

The development of manned space flight is not just a matter of replacing a warhead by a manned cabin. Suddenly, a switch is thrown between two parallel tracks, those of missile technology and those of aviation technology, and an attempt is made to move the precious human payload from one track to the other. As in all last-minute switchings, one has to be careful to assure that no derailment takes place.[8]

In the spring of 1959, while Kuettner was still signing himself the "Adam-NASA Project Engineer," he and his deputy, Earl M. Butler, began a series of triangular conferences, with Kurt H. Debus and Emil P. Bertram of ABMA's Missile Firing Laboratory at the Cape, in one corner, and Charles Mathews and Jerome B. Hammack, the Mercury-Redstone project engineer for STG, in the Langley corner. Between these informal discussions and six formal study panels inaugurated by von Braun, a consensus was supposed to arise on, among other things, the sort of emergency detection system necessary to warn of impending cataclysms in the booster and to trigger some sort of automatic ejection. Preliminary agreements on a design for an abort or safety system began early in good accord. But the uncertain reliability program, booster recovery proposal, capsule design changes, and electrical interface problems fouled the subsequent development of the Redstone abort-sensing system.[9] In this respect the Atlas was more nearly ready than the Redstone by the end of the year.

Many factors contributed to the slippage in the Mercury-Redstone schedule, but one significant cause for delay grew out of a subtle difference between ABMA and STG in their approach to pilot safety and reliability. The role of the astronaut was clearly at issue here longer than anywhere else. Conditioned by their designs for Project Adam, the Huntsville rocketmen thought of the astronaut throughout 1959 as merely an "occupant" or "passenger." The Adam proposal for an escape system during off-the-pad aborts would have ejected a biopack capsule laterally into a tank of water alongside the launch pad. Having less trust than STG in the reliability of "Old Reliable," the Redstone engineers insisted on putting safety first and making it fully automatic wherever possible. Reliability, they insisted, is only a concept and should be secondary to safety. This attitude was illustrated in the introductory paragraphs of the ABMA proposal for the Redstone emergency detection system. The author, Fred W. Brandner, began by saying that the use of missiles for transporting man would demand an automatic escape system to assure pilot safety:

This system has to rely on emergency sensors. There are an enormous number of missile components which may conceivably fail. Obviously, it would be impractical and actually unsafe to clutter up the missile with emergency sensors. However, many malfunctions will lead to identical results, and, in sensing these results and selecting the proper quantities, one can reduce the number of sensors to a few basic types.[10]



*The Mercury astronauts received their first detailed briefing on the Redstone booster at the Army Ballistic Missile Agency, Huntsville, Ala., in June 1959. Facing the briefer, Joachim P. Kuettner, the Mercury-Redstone project engineer under von Braun, are: left to right, Glenn, Shepard, Schirra, Carpenter, Slayton, Grissom, and Cooper. Kuettner touches the fin-stabilized Redstone model, explaining the purpose and construction of the carbon jet vanes barely visible below the single engine nozzle.*

Brandner proposed to measure only three basic quantities: the control system attitude and angular velocity, the 60-volt control and 28-volt general electrical power supplies, and the chamber pressure of the propulsion system. To ensure "a high degree of passenger (pilot) safety" on the Mercury-Redstone rocket, if operational limits set on these sensors should ever be exceeded the capsule would eject from the booster and be lowered by parachute.

Brandner's modest proposal stated the issue but not the solution to the general question of man-machine relationships in Project Mercury. In 1959 the technical debate was still inextricably mixed up with previous attitudes toward the precise role of man in a manned satellite. Could the pilot test the vehicle or should the vehicle test the pilot? Mercury was NASA's program and STG's responsibility, but at this stage of development the military establishment and missile industries still knew, or thought they knew, more about the technological path for man's first climb into space than NASA–STG did.[11]

From the Pentagon, for example, Brigadier General Homer A. Boushey, Director of Advanced Technology for the Air Force, had predicted in January that the most important key to space flight in the next decade would be not simply manned but rather piloted spacecraft:

> By piloted spacecraft, I refer to a vehicle wherein the pilot operates controls and directs the vehicle. This is quite a different concept from the so-called man-in-space proposal which merely takes a human "along for the ride" to permit observation of his reactions and assess his capabilities. The high-speed flight experience of the NACA and the Air Force has shown that piloted craft return research data more effectively and more economically than do unmanned vehicles. While there is a place, certainly, for automatic, instrumented vehicles, I believe man himself will prove "the essential payload" to the full utilization of space. Orbital rendezvous, controlled landing after reentry, and space missions other than the simplest sensing and reporting type, will require man. If for no other reason than that of reliability, man will more than pay his way.[12]

Boushey's percipient remarks illustrated the persistent residue of misunderstanding remaining from interagency competition for the manned satellite project in the pre-NASA, pre-Mercury period. Task Group officials felt compelled to defend the distinctive nature of Mercury and to emphasize that NASA astronauts were never intended to be passive passengers. Rather, they were to prove their full potential as pilots, within limits prescribed by the mission requirements programmed into the automatic systems. Although there were long and hard arguments within STG as to whether man should be considered "in the loop" or "out of the loop" in performing various tasks, the preponderance of NACA-bred aeronautical engineers in STG usually voted for as active an astronaut as possible.

Outside pressures from scientists and missile engineers also helped unify and consolidate opinion within STG. The distinguished research chief of Bell Telephone Laboratories and one of the fathers of communication satellites, John R. Pierce, summed up the argument for automation: "All we need to louse things up completely is a skilled space pilot with his hands itching for the controls." [13]

The problem of man-rating the Atlas was preoccupying another task force of still larger proportions than the one concerned with the Redstone. The industrial and military engineers in southern California and at the Cape who were trying to make the Atlas meet its design specifications could and did mobilize more resources than either STG or ABMA could command. A few individuals stood out as leaders in the vast effort. Kuettner's counterpart for the Air Force was Bernhard A. Hohmann, another former test pilot at Peenemuende West, who had been project engineer on the first two models of the Messerschmitt–163, one of the first rocket-powered aircraft. In August 1959, Major General Osmond J. Ritland of the Air Force Ballistic Missile Division (BMD) assigned him the job of supervising the systems engineering at Space Technology Laboratories (STL) for a pilot safety and reliability program on the Mercury-Atlas series. As Brandner did for the Redstone, D. Richard White, an STL electronics engineer,

made the preliminary designs for the Atlas emergency detection system. White was inspired, he said, "one Sunday in May when I imagined myself sitting atop that bird." Edward B. Doll, STL's Atlas project manager, could never imagine anyone foolish enough to sit on an Atlas, but he allowed Hohmann and White to proceed with their commitments.[14] STL performed an overall technical direction over the associate contractors for the Atlas similar to that performed by STG for NASA, but with significant differences. STL had not been involved in the original MX–774 design behind the Atlas, and although it became closely associated with conceptual development of Atlas as a weapon, ultimate responsibility remained with the Air Force Ballistic Missile Division. Both STL and STG were systems engineering organizations, but STG had a deeper background in research and was directly responsible for the development of the project it managed; STL had broader experience in systems engineering, missile development, and business management.

Hohmann and his assistant, Ernst R. Letsch, huddled closely with the reliability statisticians at STL, led by Harry R. Powell, and with BMD's Mercury project liaison officer, Lieutenant Colonel Robert H. Brundin, also appointed by Ritland in August 1959. But the main responsibility for detail design, development, and production work fell on the shoulders of the manufacturers, General Dynamics (formerly Convair)/Astronautics (GD/A or CV/A) of San Diego. The details, tooling, and implementation of the emergency detection or abort sensing system for the Atlas were guided by Charles E. Wilson, Tom E. Heinsheimer, and Frank Wendzel. Their boss, Philip E. Culbertson, the Mercury project manager for General Dynamics/Astronautics, conferred repeatedly and sometimes heatedly with Hohmann, Brundin, Doll, and his own factory production engineers, John Hopman, Gus Grossaint, Frank B. Kemper, and R. W. Keehn.[15]

Here, too, a triangular dialogue was going on during initial considerations for man-rating the Atlas. But STG engineers were far away, busy with other matters, and knew well how little they knew about the Atlas. NASA and the Air Force, like STG and the Army, informally had agreed to divide developmental responsibility and labor at the capsule-separation point in the trajectory. So STG was not directly involved in the tripartite workings of the so-called "BMD–STL–GD/A complex" in southern California.

Looking at Project Mercury from the West Coast in 1959 gave a set of very different perspectives on the prospects for accomplishing the program on time and in style. South of Los Angeles International Airport there was no consensus and precious little communication of the confidence felt across the continent on the coast of Virginia. But STL, Convair, and Air Force representatives at the Cape gradually diffused some of the contagious enthusiasm of STG while commuting between home and field operations. More important still, the sense of desperate military urgency to develop an operational ICBM still pervaded the factories and offices devoted to the Atlas in southern California. Motivation already mobilized might easily be transferred if only the Atlas could be proved by the end

of the year. STG was more sanguine about this forthcoming proof than the Atlas people, and NASA Headquarters seemed even more optimistic.

Perhaps symbolic of the profound Air Force distrust of the "bare Atlas" approach and indicative of lingering doubts about the competence of the STG neophytes who had stolen the march on man in space was the acronymic name imposed by Air Force officers on the abort sensing system. White and Wilson wanted to call it simply the Atlas "abort sensing system." No, someone in authority insisted, let's make the name more appropriate to STG's plans to use the Atlas "as is." [16] So this play on words, "*A*bort *S*ensing and *I*mplementation *S*ystem," became the designator for the only part of the Atlas created solely for the purpose of man-rating that missile. Reliability was truly designed into the "ASIS"; once this component was proven and installed, the Atlas ICBM should, it was hoped, be electromechanically transformed into the Mercury-Atlas launch vehicle.

*H. Julian Allen, Ames Research Center aerodynamicist who pioneered in hypersonic wind tunnel development and provided the concept of blunt reentry bodies, which was a major contribution to ballistic missile nose-cone technology and to the Mercury capsule, briefs a delegation from the National Aeronautics and Space Council visiting Ames on August 3, 1959. Visitors are, left to right, John T. Rettaliata, Alan T. Waterman, Executive Secretary Franklyn W. Phillips, William A. M. Burden, NASA Administrator T. Keith Glennan, and Center Director Smith DeFrance.*



Astronaut Donald K. Slayton defended his prospective role and STG's stance on the issue of automation when he addressed his brethren in the Society of Experimental Test Pilots on October 9. By his own admission, these were some "stubborn, frank" words:

> First, I would like to establish the requirement for the pilot. . . . Objections to the pilot range from the engineer, who semi-seriously notes that all problems of Mercury would be tremendously simplified if we didn't have to worry about the bloody astronaut, to the military man who wonders whether a college-trained chimpanzee or the village idiot might not do as well in space as an experienced test pilot. The latter is associating Mercury with the Air Force MISS or Army Adam programs which were essentially man in a barrel approaches. The answer to the engineer is obvious and simple. If you eliminate the astronaut, you can see man has no place in space. This answer doesn't satisfy the military skeptic, however, since he is not questioning the concept of a man in space but rather what type man. I hate to hear anyone contend that present day pilots have no place in the space age and that non-pilots can perform the space mission effectively. If this were true, the aircraft driver could count himself among the dinosaurs not too many years hence.
>
> * * *
>
> Not only a pilot, but a highly trained experimental test pilot is desirable . . . as in any scientific endeavor the individual who can collect maximum valid data in minimum time under adverse circumstances is highly desirable. The one group of men highly trained and experienced in operating, observing, and analyzing airborne vehicles is the body of experimental test pilots represented here today. Selection of any one for initial space flights who is not qualified to be a member of this organization would be equivalent to selecting a new flying school graduate for the first flight on the B–70, as an example. Too much is involved and the expense is too great.[17]

Slayton's defense of Mercury before his professional colleagues outside NASA was echoed time and again in the next two years by NASA spokesmen. But many critics remained skeptical because it was obvious that Mercury was being designed to fly first without man. Flight controllers and electronics engineers who had specialized in ground control of supersonic interceptors and who had confidence in the reliability of remote control of automatic weapon systems were the least enthusiastic about allowing the pilots to have manual overrides. Christopher C. Kraft, Jr., the chief flight director for STG, preceded Slayton on the same program at the meeting of the experimental test pilots. He reviewed the range network to be provided and the operational plan to be used for the Mercury orbital mission. At that time, Kraft circumspectly avoided any public indication of his personal views on the role the astronaut would play, but years later he confessed his bias:

> The real knowledge of Mercury lies in the change of the basic philosophy of the program. At the beginning, the capabilities of Man were not known, so the systems had to be designed to function automatically. But with the addition of Man to the loop, this philosophy changed 180 degrees since primary success of the mission depended on man backing up automatic equipment that could fail.[18]

In public, the managers of NASA and of Mercury, who had to request funds and justify their actions before Congress and the people, appeared as optimistic as possible and pointed out what could be achieved with successful missions. Privately, they not only had doubts, they cultivated a group of professional pessimists whose job it was to consider every conceivable malevolent contingency. John P. Mayer, Carl R. Huss, and Howard W. Tindall, Jr., first led STG's Mission Analysis Branch and set a precedent for spending ten times as much effort on planning for abnormal missions as for normal ones.[19]

Although not always obvious to STG, there also were differences in attitudes within the space medicine fraternity. Since mid-1958, men like Siegfried J. Gerathewohl and George R. Steinkamp had led the school of thought that believed that man was more nearly machine-rated than machines were man-rated. Conversely, the chief of the space medicine division of the Air Force's School of Aviation Medicine, Colonel Paul A. Campbell, influentially asserted his belief that "in these past two or three years the situation has suddenly changed, and the machine capability has advanced far beyond man's capability." [20] Other biologists and medical college specialists also had doubts about the peculiar combination of stresses—from high to zero to high g loads—that the man in Mercury must endure. Whatever the majority medical opinion might have been, the Task Group felt itself beleaguered by bioastronautical specialists who wanted to "animal-rate" the space flight machines all the way from amoebas through primates before risking a man's life in orbit.

## Approaches to Reliability

"Reliability" was a slippery word, connoting more than it denoted. Yet as an engineering concept it had basic utility and a recognized place in both aviation and missile technology. The quest for some means of predicting failures and thereby raising the odds toward success began modestly as a conscious effort among STG and McDonnell engineers only in mid-1959, after design and development work on major systems was well under way. Other engineering groups working in support of Project Mercury also began rather late to take special care to stimulate quality control and formal reliability programs for booster and capsule systems. Mercury would never have been undertaken in the first place if the general "state-of-the-art" had not been considered ready, but mathematical analyses of the word "reliability" both clarified its operational meaning and stirred resistance to the statistical approach to quality control.

The fifties had witnessed a remarkable growth in the application of statistical quality control to ensure the reliability of weapon systems and automatic machinery. The science of operations analysis and the art of quality management had emerged by the end of the decade as special vocations. Administrator Glennan himself, as president of Case Institute of Technology, had encouraged the development over the decade of one of the nation's foremost centers for operations

research at Case.[21] STG executive engineers studied an almost pedestrian example of these new methods for more scientific management of efficiency; it was one given by an automobile executive who compared the reliability of his corporation's product over 32 years before 1959:

> If the parts going into the 1959 car were of the same quality level as those that went into the 1927 car, chances would be even that the current model would not run.
>
> This does not mean that the 1927 car was no good. On the contrary, its quality was excellent for that time. But it was a relatively simple product, containing only 232 critical parts. The 1959 car has 688 such parts. The more the critical parts, the higher the quality level of each individual part must be if the end product is to be reliable.[22]

In view of the fact that estimates showed over 40,000 critical parts in the Atlas and 40,000 more in the capsule, the awesome scale and scope of a reliability program for Mercury made it difficult to decide where to begin.

To organize engineering design information and data on component performance, someone had first to classify, name, or define the "critical parts." To create interrelated systems and to analyze them as separate entities at the same time was difficult. The Space Task Group and McDonnell worked on creation at the expense of analysis through 1959. Gradually NASA Headquarters and Air Force systems engineers steered attention to certain "semantic" problems in the primitive concepts being used for reliability analyses. For instance, what constitutes a "system"? How should one define "failure"? What indices or coefficients best "measure" overall system performance from subsystem data?[23]

These and other features of reliability prediction were so distasteful to creative engineers that many seriously questioned the validity and even the reliability of reliability predictions. "Reliability engineering," admitted one apologist in this field, "may seem to be more mysticism and black art than it is down-to-earth engineering. In particular, many engineers look on reliability prediction as a kind of space-age astrology in which failure rate tables have been substituted for the zodiac."[24] Around STG this skeptical attitude was fairly representative. But at NASA Headquarters, Richard E. Horner, newly arrived in June 1959 as Associate Administrator and third man in command, had brought in a small staff of mathematicians and statisticians. It was led by Nicholas E. Golovin, who transferred from the Air Force to NASA some of the mathematical techniques lending quantitative support to demands for qualitative assurance. Theory-in-Washington versus practice-at-Langley were in conflict for a year until the nature of "reliability" for pilot safety on the one hand and for mission success on the other became more clearly understood by both parties. The pressure exerted by Golovin and NASA Headquarters to get the Task Group and McDonnell to change its approach to raising reliability levels became a significant feature in redesign and reliability testing during 1960.[25]

Scientists, statisticians, and actuaries, working with large populations of

entities or events, had long been able to achieve excellent predictions by defining reliability as a probability, but in so doing they sacrificed any claim to know what would happen in a unique instance. Engineers and managers responsible for a specific mission or project tended to ridicule probability theory and to call it invidiously "the numbers game." Being limited to a small set of events and forced by time to overlap design, development, test, and operations phases, they could not accept the statistical viewpoint. They demanded that reliability be redefined as an ability. The senior statistician at Space Technology Laboratories for the Atlas weapon system, Harry Powell, recognized and elaborated on this distinction while his colleagues became involved with man-rating the Atlas. His remarks indicated that STL and Convair/Astronautics faced the same divergence of opinion that NASA Headquarters and STG confronted:

> If reliability is to be truly understood and controlled, then it must be thought of as a device, a physical property which behaves in accordance with certain physical laws. In order to insure that a device will have these physical properties it is necessary to consider it first as a design parameter. In other words, reliability is a property of the equipment which must be designed into the equipment by the engineers. *Reliability cannot be tested into a device and it cannot be inspected into a device; it can only be achieved if it is first designed into a device.* Most design engineers are acutely aware that they are under several obligations—to meet schedules, to design their equipment with certain space and weight limitations, and to create a black box (a subsystem) which will give certain outputs when certain inputs are fed into it. It is imperative that they also be aware of their obligation to design a device which will in fact perform its required function under operation conditions whenever it is called upon to do so.[26]

There is a rule in probability theory that the reliability of a system is exactly equal to the product of the reliability of each of its subsystems in series. The obvious way to obviate untrustworthy black boxes was to connect two black boxes in parallel to perform the same function. In other words, redundancy was the technique most often used to ensure reliability.

After the cancellation of Mercury-Jupiter, Kuettner and others at ABMA set about a serious effort to develop a parachute system to recover the Redstone booster. They also began to concentrate on the simplifications necessary for the sake of reliability to custom-build a man-rated Redstone. Starting with the advanced, elongated version of the rocket, which had been renamed the "Jupiter-C" in 1956 for the Army's ablation research on reentry test vehicles, Kuettner called upon the expertise of all who could spare time from the Saturn program to help decide how to man-rate their stock. The fundamental change made to the Jupiter-C airframe was the elimination of its staging capability. Other modifications stripped it of its more sophisticated components while permitting it to retain greater performance characteristics than the original single-stage Redstone.[27]

The designers of the Redstone and Jupiter missile systems proposed an extensive list of basic modifications to adapt the vehicle to the Mercury capsule. The

elongated fuel tanks of the Jupiter-C had to be retained for 20 extra seconds of engine burning time, especially since they decided to revert to alcohol for fuel rather than use the more powerful but more toxic hydyne that fueled the Jupiter-C. Another high-pressure nitrogen tank to pressurize the larger fuel tank and an auxiliary hydrogen peroxide fuel tank to power the engine turbopump also had to be added. To increase the reliability of the advanced Redstone, they had to simplify other parts of the Jupiter-C system. Instead of the sophisticated autopilot called ST–80, one of the first inertial guidance systems (the LEV–3) was reinstalled as the guidance mechanism. The after unit of the payload on the old Redstone, which had contained a pressurized instrument compartment, became the permanent forebody of the main tank assembly, there being no need to provide terminal guidance for the new payload. A spacecraft adapter ring likewise had to be designed to simplify interface coordination and to ensure clean separation between capsule and booster. At the other end of the launch vehicle it was necessary to use the most recent engine model, the A–7, to avoid a possible shortage of spare parts. Hans G. Paul and William E. Davidson, ABMA propulsion engineers, took the basic responsibility for "man-rating" this engine.[28]

Although STG engineers bought the Redstone in the first place because it was considered an "off-the-shelf" rocket, they gradually learned through Hammack's liaison with Butler that the Mercury-Redstone was in danger of being modified in about 800 particulars, enough to vitiate the record of reliability established by the earlier Redstones and Jupiter-Cs. Too much redesign also meant reopening the Pandora's box of engineering "trade-offs," the compromises between overdesign and underdesign. Von Braun's team tended in the former direction; Gilruth's in the latter. To use Kuettner's distinction, ABMA wanted "positive redundancy" to ensure aborts whenever required, whereas STG wanted more "negative redundancy" to avoid aborts unless absolutely essential.[29] This distinction was the crux of the dispute and the essence of the distinction between "pilot safety" and "mission success."

On July 22, 1959, STG engineers received a group of reliability experts from von Braun's Development Operations Division at Huntsville. Three decades of rocket experience had ingrained strongly held views among the 100 or so leaders of this organization about how to ensure successful missions. The ABMA representatives told STG that they did not play the "numbers game" but attacked reliability from an exhaustive engineering test viewpoint. Their experience had proved the adequacy of their own reliability program, carried out by a separate working group on a level with other engineering groups and staffed by persons from all departments in the Development Operations Division of ABMA. In conference with design engineers, ABMA reliability experts normally set up test specifications and environmental requirements for proving equipment compliance. STG felt sympathetic to this approach to reliability, but systems analysts at NASA Headquarters did not.

As for the prime contractor's reliability program, in the first major textbook studied by the astronauts, McDonnell's "Project Mercury Indoctrination" manual, distributed in May 1959, the pilots read these reassuring words:

> The problem of attaining a high degree of reliability for Project Mercury has received more attention than has any other previous missile or aircraft system. Reliability has been a primary design parameter since the inception of the project.[30]

Accompanying reliability diagrams showed over 60 separate redundancies designed into the various capsule systems, allowing alternate pilot actions in the event of equipment malfunctions during an orbital mission.

McDonnell specified three salient features of its reliability program in this preliminary indoctrination manual. First, by making reliability a design requirement and by allowing no more than a permissible number of failures before redesign and retesting were required, reliability was made a conscious goal from the beginning of manufacture. Second, five separate procedures were to implement the development program: evaluations, stress analyses, design reviews, failure reporting, and failure analysis. Third, reliability would be demonstrated finally by both qualification and reliability testing.

These assurances did not seem adequate; STG, as well as NASA-Washington, requested McDonnell to clarify its reliability policy in more detail and to hold a new symposium in mid-August to prove the claim that "reliability is everybody's business at McDonnell." McDonnell responded by changing its "design objective" approach to what may be called a "development objective" approach. The new program, drawn by Walter A. Harman and Eugene A. Kunznick, explicitly set forth mean times to failure and added more exhaustive demonstrations, or "life tests," for certain critical components. More fundamental assumptions were made explicit, such as: "the reliability of the crew is one (1.0)," and "the probability of a catastrophic explosion of the booster, of any of the rockets, of the reaction control system, or of the environmental control system is negligible." [31] McDonnell's presentation at this symposium stressed new quality control procedures and effectively satisfied STG for the moment. Golovin and his NASA Headquarters statisticians were pleased to note refinement in sophistication toward reliability prediction in the capsule contractor's figures for the ultimate 28-hour Mercury mission. At the August 1959 reliability symposium, McDonnell assigned impressively high percentage figures as reliability goals for both mission and safety success:

| | *Mission* | *Safety* |
|---|---|---|
| Boost | .7917 | .9963 |
| Orbit | .9890 | .9999 |
| Retrograde | .9946 | .9946 |
| Reentry | .9992 | .9992 |
| Overall | .7781 | .9914 |

To John C. French, who began the first reliability studies for Gilruth's group, this kind of table represented the "numbers game," mere gambling odds that might deceive the naive into believing that if not the fourth, then the third, decimal place was significant. French was an experienced systems engineer who recognized that numbers like these did mean something: obviously the authors felt the weakest link in the chain of events necessary to achieve mission success was the launch vehicle. McDonnell believed the safety of the astronaut would be ensured by the escape system, but the coefficient ".7917" diluted the confidence in overall mission success to ".7781." McDonnell and STG agreed that the onus was on the Atlas to prove its safety and reliability as a booster for the Mercury mission.

That point was not disputed by the men responsible for the Atlas. They professed even less confidence in their product for this purpose than the capsule contractor had. Not until November 13, 1959, did representatives of the Air Force Ballistic Missile Division and Space Technology Laboratories visit Langley to present in detail their case for a thoroughgoing plan to man-rate the Atlas as a Mercury booster. Harry Powell had prepared a carefully qualified chart that estimated that the reliability of the Mercury booster would reach approximately 75 percent only in mid-1961, and the first upbend (at about 86 percent) on that curve was to occur another year later.[32] Such pessimism might have been overwhelming to STG except that no abort-sensing system was yet computed as a factor in this extrapolation. Also STG and STL agreed never to entertain the idea of "random failure" as a viable explanation.

Because aircraft designers and missile experts held different opinions about which systems should be duplicated, redundancy itself was often a subject of dispute. Passenger aircraft were provided with many redundant features, including multiple engines and automatic, semi-automatic, and manual control systems, so that commercial flight safety had been made practically perfect. But in the military missile programs of 1959, redundancy to ensure mission success had been relegated to the duplication of the complete missile, "by making and launching enough to be sure that the required number will reach each target." [33] In the age of "overkill," one out of four, for instance, might be considered quite sufficient to accomplish the destructive mission of the ICBM. Both McDonnell and the Task Group placed more faith in quality control procedures and in redundant system development than in mathematical models for reliability prediction during design.

In the course of further symposia and conferences during the autumn, the Space Task Group, working with military systems analysts and industrial quality controllers, learned more than it taught about improving reliability programs. Abe Silverstein, whose Headquarters office was retitled Space Flight Programs (instead of Development) at the end of the year, was especially eager to see STG set up its own reliability program, with procedures for closer monitoring of subcontracts.[34]

But before STG could presume to teach, it had to learn much more about the mechanics of the Redstone and the Atlas. Mathews had his own mathematicians check the case histories for failures of every Redstone, Jupiter, and Atlas that had ever been launched. A statistical population of over 60 Redstone and about 30 Atlas launches yielded clinical diagnoses for generalizing about the most likely ways these boosters might fail. Gerald W. Brewer, Jack Cohen, and Stanley H. Cohn collected much of this work for STG, and then Mathews, Brandner of ABMA, White of STL, and others formulated some ground rules for the development of the two abort-sensing systems.

All the investigators were pleasantly surprised to find relatively few catastrophic conditions among the failures. Their biggest problem was not what to look for or when to allow the escape rocket to blast away but rather how to avoid "nuisance aborts." Such unnecessary or premature escapes would arise from overemphasis on pilot safety or "positive redundancy" at the expense of mission success. Long arguments ensued over several questions: How simple is safe? How redundant can you get and still have simplicity? How do you design a fail-safe abort-sensing system without overdesigning its sensitivity to situations less than catastrophic?[35]

Without trying to define every term, Mathews and his associates agreed that only imminent catastrophic failures were to be sensed, that reliability should be biased in favor of pilot protection, and that all signals from abort sensing should be displayed in the spacecraft. Application of these ground rules to the Redstone led to development of an automatic abort-sensing system (AASS) that sensed "downstream" or fairly gross parameters, each of which was representative of many different types of failures. Merely "critical," as opposed to "catastrophic," situations were not allowed to trigger the escape system automatically. Such merely "critical" situations as partial loss of thrust, a fire in the capsule, deviation from flight path, or loss of tank pressure might possibly be corrected or tolerated. But catastrophic situations were defined as existing where there were no seconds of time for intelligent decisions, corrective actions, or manual abort. The abort system for the Mercury-Redstone sensed and was activated by such typical catastrophic situations as excessive attitude deviations or turning rates (leading to high angles of attack during high dynamic pressures and resulting in a structural breakup), as sudden loss of tank or bulkhead differential pressure in pressure-stabilized structures, as loss of electrical power in the control and instrument system, and as loss of thrust immediately after liftoff.[36]

If any of these situations should arise, the automatic abort-sensing system was supposed to initiate an explosively rapid sequence of events. First, the engine of the Redstone would cut off (except during the initial moments over the launch site). Then the capsule would separate from the booster. And this would be followed by the ignition of the escape rocket, with acceleration up and away from the booster, and finally by the normal sequencing of events in the recovery phase of the launch profile.

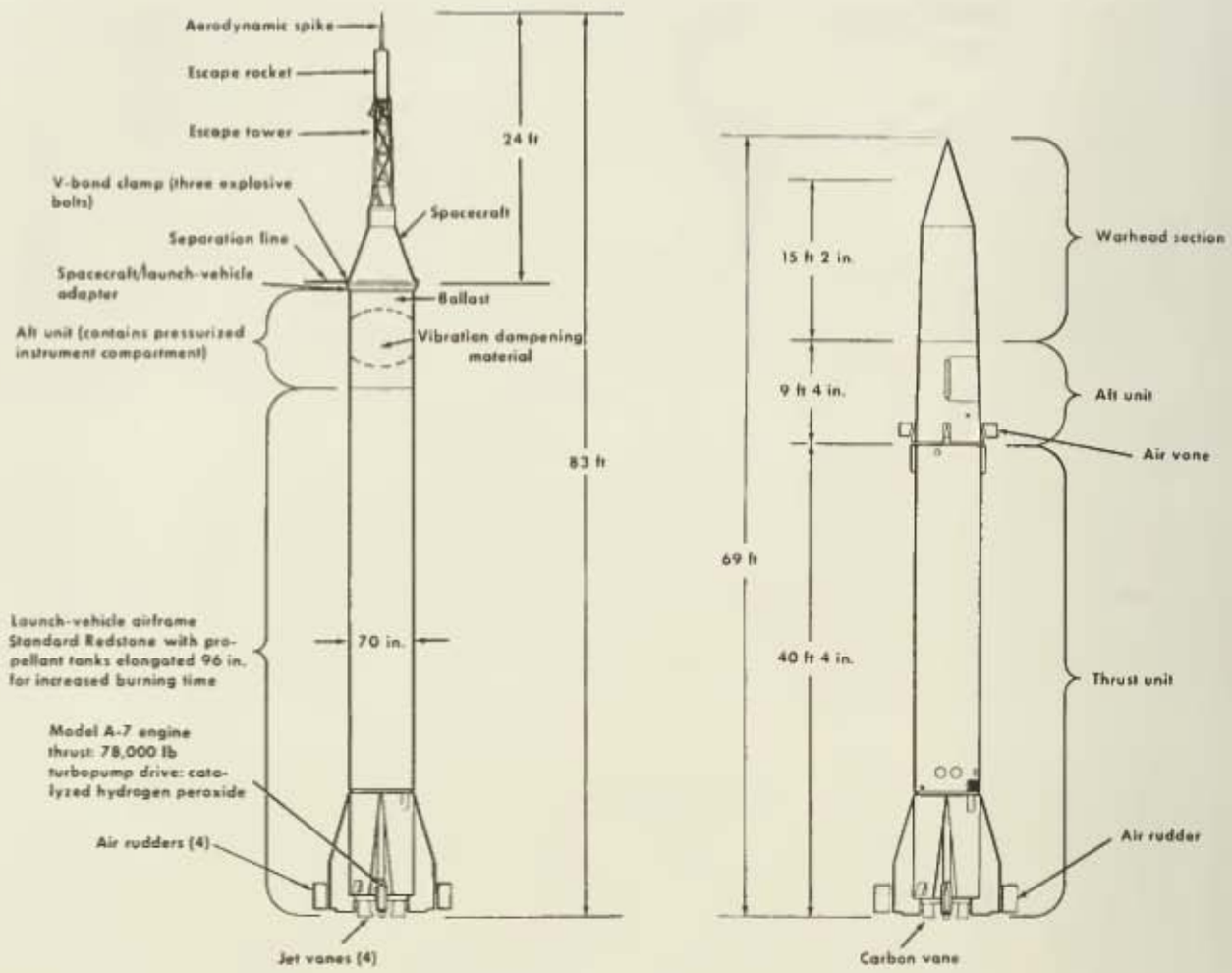
During August, September, and October, the Task Group improved its understanding of the interrelated parts and procedures being developed for Mercury. New definitions were formulated in hardware and words. Some old worries—the heatshield, for instance—were abandoned as newer concerns replaced them. The success of Big Joe and the promise of Little Joe shots promoted confidence and sustained enthusiasm. At the end of this period optimistic forecasts were the rule, not only for booster readiness but also for firm operational schedules. The first Mercury-Redstone and Mercury-Atlas qualification flight tests were scheduled for launchings in May 1960. Even the final goal of Project Mercury, the achievement of manned orbital flight around Earth, still appeared possible by March 1961.[37]

But as autumn blended into winter in 1959, optimism cooled along with the weather. The job of keeping snow clear of its own drive was difficult enough, but heavier equipment than that possessed by the Task Group was necessary to plow aside the drifts that sometimes covered the streets of interagency cooperation. In particular, the Mercury-Redstone schedule began to look progressively more snowbound in the early winter of 1959, largely because the capsule and the Atlas commanded primary attention.

At the end of August, Gilruth had proposed to Major General John B. Medaris, commanding ABMA, that the first attempt at a Mercury-Redstone launch from the Cape be set for February 1, 1960. This proposal represented a slippage of about four months since February 1959, when the initial understanding between ABMA and STG had been reached. But the prospects for rapid accomplishments in the next six months were brighter at Langley than at Huntsville, St. Louis, or the Cape. Plans to use eight Mercury-Redstones for ballistic training flights between February and October 1960 were still in effect, and STG also hoped to complete six manned Redstone flights by March 1961 before launching the first of the manned Mercury-Atlas configurations. Such optimism was not entirely the result of youthful naivete or of underestimates of complexity. In large part, target dates were set deliberately at the nearest edge of possible completion periods to combat Parkinson's Law regarding bureaucratic administration, that work expands to fill the time allotted for its completion.[38]

Much of the fault for Redstone slippages must revert to STG for having canceled the Mercury-Jupiter series rather precipitously, thereby unceremoniously relegating the 4000 members of von Braun's division at Huntsville almost to "task element" status as far as Mercury was concerned. Although the Jupiter program per se was being phased out at ABMA, its sires, who sparked the entire Army Ordnance team, were sensitive to criticism of their strange love for space travel.[39] STG engineers should not have been surprised that the cancellation of the Mercury-Jupiter series would cause a reaction in Huntsville that would reverberate to the Cape and through Washington.[40]

Although NASA Headquarters had carefully coordinated STG's recommendation in this matter, many other factors contributed to the change in the Mercury




*Schematic of Mercury-Redstone.*

program management plans that forecast the slip of MR–1 past MA–1 on the flight test schedule. There were at least three technical reasons for the Mercury-Redstone slippages as well as several other, perhaps more important, psychological and policy-planning reasons for this change in the "progressive buildup of tests" principle.

Foremost among all causes of delay was the fact that the pacing item, McDonnell's production model of the Mercury capsule, took longer to build than anyone supposed it would.[41] Because systems integration within the spacecraft was lagging by several months, every other area would be delayed also to some degree. Secondly, the design and development of the abort-sensing systems for the Redstone and Atlas were attacked separately and not cross-fertilized. The basic dispute over safety versus success, or positive versus negative redundancy, could be settled only with actual flight test experience.

A third technical reason for the fact that the Redstone team, with its ready and waiting boosters, failed to lead off the series of qualification flight tests was

related to the Teutonic approach to reliability. Long years of experience with rockets, together perhaps with some native cultural concern for meticulous craftsmanship, gave the von Braun group high confidence that most so-called "reliability" problems could be obviated by hard work, more flight tests, and intensive engineering attention to every detail. Elaborate operational checkouts were to be made at Huntsville and the Cape. STG agreed to these procedures in August, but by November time was clearly in contention between Huntsville and Langley. The Task Group wanted to launch its first three Redstones for Mercury during May and June 1960, but if this were possible, it was hardly advisable from ABMA's point of view.[42]

By then, however, this could be considered a family dispute among stepbrothers within NASA. On October 21, 1959, President Eisenhower announced his decision, pending congressional approval, to transfer the von Braun group and the Saturn project from ABMA to NASA. If this decision solved a morale problem among members of the Development Operations Division at ABMA, it undoubtedly complicated certain institutional and political problems. Jockeying for position probably intensified rather than abated, as plans for the future use of the Saturn launch vehicle overshadowed Mercury for the moment. Another five months were required to complete a transfer plan, and eight months would elapse before the official transfer was completed on July 1, 1960.[43]

Although the plans for the escape of a pilot from a malfunctioning Redstone were complex, plans for a similar emergency detection system on the Atlas were several times more complicated. Three engines, rather than one, with an overall range and thrust capability well over three times greater, and with guidance, gimbaling, and structural separation mechanisms far more complex than those to be used on the Redstone—these were some of the factors that put the problem of man-rating the Atlas on a higher plane of difficulty. The Mercury capsule escape system was, of course, the same for both boosters, but the emergency detection systems had to be tailored to the differences between the launching vehicles. The single-stage Redstone was a piece of battlefield artillery that could stand on its own four fins, for example, whereas the fragile "gas-bag" Atlas would crumple if not pressurized. And in flight, the Atlas' outboard engines must stage properly and drop away from the central sustainer engine before the escape tower could be jettisoned.

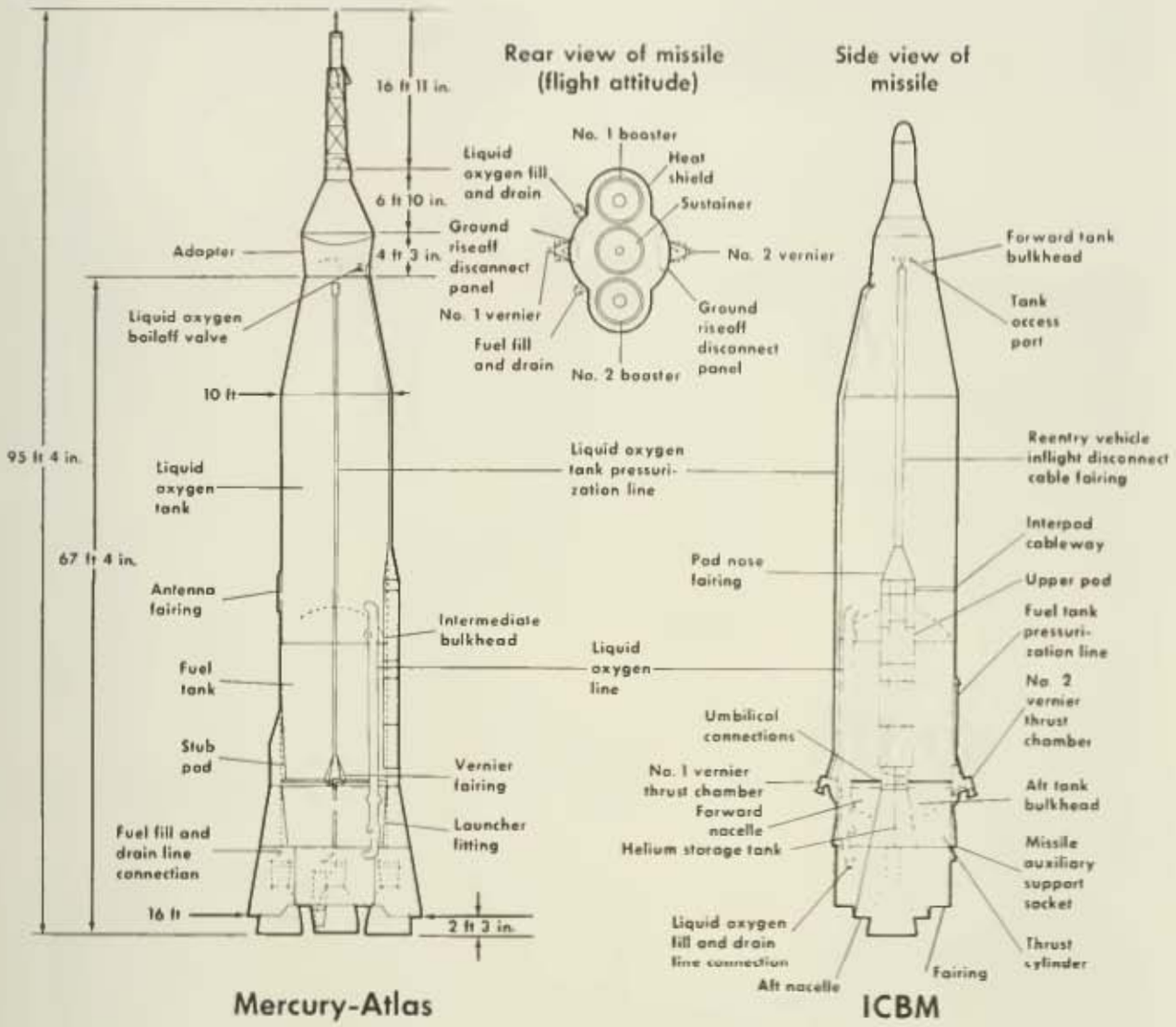
While Charles Wilson and his crew at Convair in San Diego worked out the detailed design and hardware for ASIS, Richard White led Space Technology Laboratories through more detailed analytical studies and simulation tests at El Segundo. Their concurrent efforts ensured that the airborne emergency detection system for the Mercury-Atlas evolved, as Powell insisted it must, with the steadfast goal of reliability. Inspection and test programs were inaugurated separately by Hohmann, beginning in October, but reliability was designed into the ASIS black box from May onward. Wilson and White soon discovered that their biggest problem concerned the prevention of recontact between booster and capsule after

separation. Alan B. Kehlet and Bruce G. Jackson of STG had the primary responsibility to determine the proper thrust offset of the escape rocket and to ensure against recontact, but "Monte Carlo" probability analyses were done by both Convair and the Space Task Group.[44]

In addition to the ASIS, the Atlas D had to be modified in a number of other ways before it could carry a man. Because the Mercury-Atlas configuration was taller by approximately 20 feet than the Atlas D weapon system, the rate gyro package for the autopilot had to be installed 20 feet higher on the airframe, so it would sense more precisely the rate of change of booster attitude during launch. The Atlas would not need posigrade rockets to assist separation because the Mercury capsule would embody its own posigrade rockets inside its retrorocket package. Because the capsule's posigrade rockets could conceivably burn through the thin skin of the liquid-oxygen dome, a fiber-glass shield covering the entire dome was attached to the mating ring. The two small vernier rocket engines, which on the ICBM had thrust on after sustainer engine cutoff, or "SECO," for last-minute trajectory corrections, were regoverned to delete the "vernier solo" phase of operation, thus saving more weight and complexity. In addition to the use of older, more reliable types of valves and special lightweight telemetry, only one other major booster modification was considered at first. The man-rated Atlas D would use the so-called "wet start" instead of the newer, faster "dry start" method of ignition. A water pulse sent ahead of the fuel into the combustion chambers would effect slower and smoother initial thrust buildup, minimizing structural stress on the engine before liftoff. This change saved approximately 60 pounds, by enabling the use of a thinner skin gauge in the Atlas airframe. But the "thin-skinned" Atlas soon proved to be too thin-skinned, and the weight saved was lost again in 1961, when a thicker skin was found to be essential in the conical tank section just under the capsule. The longer, lighter spacecraft payload proved a cause of additional dynamic loads and buffeting problems, calling for more strength in the Atlas forebody.[45]

After additional study of the idiosyncracies of the Atlas missile, Mathews, Wilson of Convair, and White decided on the parameters most in need of monitoring for abort indications: (1) the liquid oxygen tank pressure, (2) the differential pressure across the intermediate bulkhead, (3) the booster attitude rates about all three axes, (4) rocket engine injector manifold pressures, (5) sustainer hydraulic pressure, and (6) primary electrical power.

Dual sensors gauging each of these catastrophic possibilities were fairly easily developed. If any one of these conditions should arise or any system should fail, the ASIS would by itself initiate the explosive escape sequence. But any one of four men with their fingers poised over pushbuttons also could abort the mission: the test conductor, the flight director in the control center, the range safety officer, or the astronaut with his left thumb would be able to decide if and when the escape rocket should be ignited. But these manual abort capabilities were only supplements, with built-in time delays, to the automatic abort sensing and implementation




*Schematic of Mercury-Atlas D.*

system. During the portion of the flight powered by the Atlas, human judgment was to be secondary to a transistorized watchdog autopilot. Their moral obligation to pilot safety made the Atlas redesigners reduce man-control to this minimum. Culbertson later explained, "While it was true that mission success provided pilot safety, provision for pilot safety did not always improve the probability of mission success."[46]

One of the most important analytical tasks in man-rating the Atlas was the careful and continuous study of the mathematical guidance equations for the launch phase of all the missions. Three men at Space Technology Laboratories shared this responsibility, C. L. Pittman, Robert M. Page, and Duncan McPherson. While Convair was learning that it cost approximately 40 percent more to build a man-rated Mercury-Atlas than a missile system, STL's mathematicians and systems engineers, like Hohmann and Letsch, were working out their differences on how to control quality and augment reliability. By the end of 1959, Hohmann

had sold his plans for pilot safety. They were based on applying supercharged aircraft production techniques to industrial practices for military missile production. To live with the Atlas required no less and eventually much more.[47]

## Critical Components of the Capsule

Basic as the boosters were for successful manned space flight, they were not the only machines that had to be certified for safety before a man's life could be entrusted to them. The capsule with all its systems and subsystems, designed to operate automatically on unmanned test flights at first, would also have to have reliable provisions for operation with a normal, or even with an incapacitated or unconscious, man aboard. Man-rating the spacecraft, therefore, involved the paradoxical process of dehumanizing it first for rehumanizing later.

When the seven Mercury astronauts first visited the McDonnell Aircraft Corporation laboratories and factory, for three days in May 1959, each was handed an indoctrination manual and given opportunities to inspect the mockup capsule and to review the requests for alterations made by the Mockup Review Board in March. Immediately they expressed some uneasiness about the poor visibility afforded by the two remotely placed portholes and about the difficulty of climbing out the bottleneck top of the capsule.[48] So, based on these and numerous other criticisms expressed by the men for whom these machines were being built, redesign studies were begun.

Just as Maxime Faget was the chief NACA–NASA designer of the capsule configuration and mission concept, so John F. Yardley, his closest counterpart in the McDonnell organization, was the chief developer of the Mercury capsule. Neither Faget nor Yardley was the nominal leader of the vast team within which each worked, but both animated the technical talents of their colleagues, from design through the final development stages of the Mercury hardware. John Yardley held a master's degree in applied mechanics, had worked for McDonnell since 1946 as a stress analyst, strength engineer, and project leader, and he was exceptionally talented in his capacity for work and for synthesizing technical knowledge. By telephone, teletype, and face to face, Faget and Yardley consulted each other about the multitude of detailed design and development decisions involved in production throughout 1959. But their bilateral agreements were restricted to details. Larger decisions regarding the development of systems or interaction between subsystems were reserved for the 17 different working groups in STG and the 10 or so at McDonnell. James Chamberlin instigated this capsule coordination system and gradually replaced Faget in relations with Yardley during the next year.[49]

In 1959 the McDonnell Aircraft Corporation became the 100th-largest industrial company in the United States, employing approximately 24,000 people to produce goods (primarily the F4H–1 Phantom twin-jet fighter for the Navy) and services (mainly computer time, electronic equipment, and systems engineering)

valued at $436 million. Within this corporate context, the contract with NASA for about $20 million to manufacture 12 or more spacecraft, requiring only 300 or 400 workers and representing less than five percent of McDonnell's annual sales volume, appeared rather minuscule. The president of the corporation, J. S. McDonnell, in September 1959 wrote for his twentieth annual report to stockholders that "there is no need to stampede away from the *air*craft business." [50]

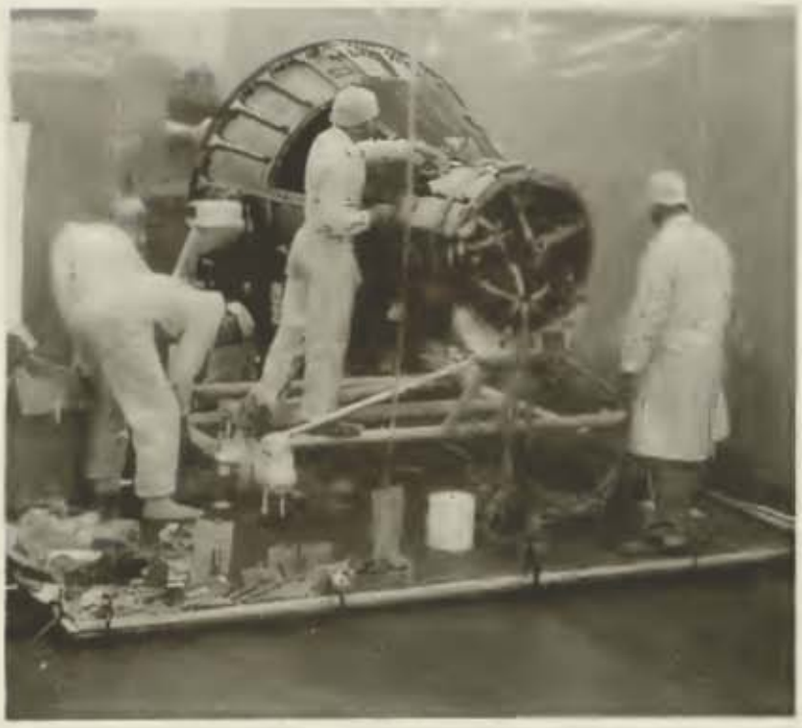
When the prime contract for Mercury was awarded to McDonnell, the Corporation's vice-president for project management, David S. Lewis, assigned Logan T. MacMillan, a tall, tactful test pilot and mechanical engineer with a winning manner, to be companywide project manager with authority to mobilize the resources of the Corporation for the new venture. MacMillan, of the same age and rank as Faget, soon found it difficult to reconcile McDonnell's development and production phases with NASA's concurrent research and test phases. Time, cost, and quality control were interdependent, and now the astronauts and STG had called for major design changes in the window size and placement, the side entrance-exit hatch, the instrument panel, and switch accessibility. To his top management, MacMillan reported on July 18, 1959:

> The Space Task Group is a rather loosely knit organization of former Research Engineers. The Coordination Office is an attempt to channel and control information and requirements against MAC more closely and is a good move. It is clear, however, regardless of whether or not it succeeds, the NASA philosophy of investigation and approval of the smallest technical details will continue, and request for changes will also continue. We will continue to handle this by being responsive to requests for studies and recommendations and to be as flexible as we possibly can to incorporate changes. It is imperative that we continue to improve our capability to make these studies promptly, submit change proposals to cover the increased work as soon as possible, and evaluate the effect of changes on delivery schedules rapidly.[51]

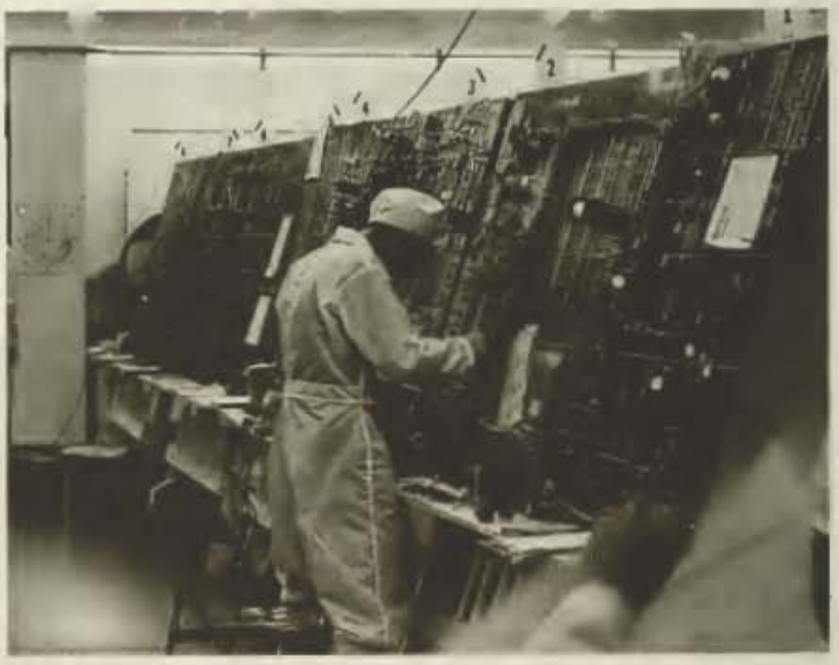
A month later MacMillan complained by teletype message directly to Paul E. Purser that coordination meetings were being held too frequently for effective action on items from preceding meetings. He suggested that later meetings be scheduled "for one month from time minutes are received at MAC." But the pace did not slow significantly; the finish line simply moved farther away.

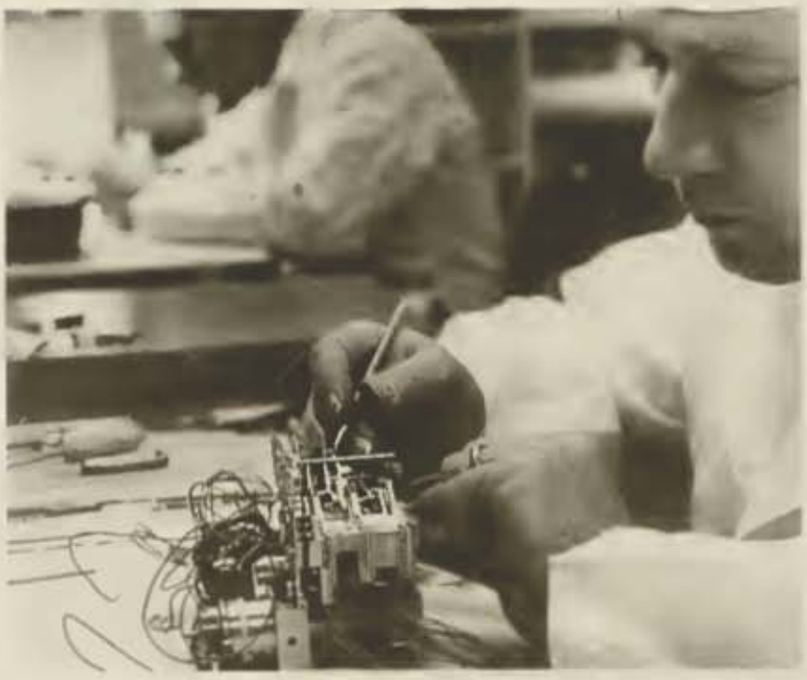
MacMillan and Yardley, together with Edward M. Flesh and William Dubusker, two older, more experienced production engineers, supervised the bulk of the load for McDonnell in tooling up, making jigs and fixtures, and organizing their craftsmen and procedures for production. Kendall Perkins, McDonnell's vice-president for engineering, had deliberately assigned Yardley and Flesh, combining youthful enthusiasm and experienced caution, to start the manufacture—literally the handmaking—of the first spaceframe. The subsequent design and technical development at McDonnell was carried out under their direction.[52]

By July 1959, Dubusker, the tooling superintendent, had completed McDonnell's first surgically clean "white room" for the later manufacturing phases, had taken on the job of manufacturing manager for Mercury, and had moved some



*White-room manufacturing standards typified the revolution in upgrading of precision and reliability in manufacturing and checkout techniques. At the McDonnell plant, white-room conditions prevail (left) as fabrication proceeds on a spacecraft; (below) part of a spacecraft's seven miles of wire is installed on a breadboard; and (below, left) a technician assembles a compact spacecraft clock.*





200 workmen onto the new production lines. Learning to fusion-weld titanium .010-inch thin in an encapsulated argon atmosphere was his first challenge and proudest accomplishment. But before the year was over, Dubusker had to contend with retooling for other unusual materials, with rising requirements for cleanliness, with stricter demands for machined tolerances, and with higher standards for quality control.

Flesh, the engineering manager, and Dubusker drew on all of McDonnell's experience with shingled-skin structures around jet afterburners for heat protection. Their machinists had previously worked with the patented metal, René 41, a nickel-base steel alloy purchasable only from General Electric, but arc-jet tests of the afterbody shingles on the outer shell of the capsule showed a need for some ingenious new fabricating techniques.[53]

While Yardley and Flesh concentrated on developing the most critical components for the Mercury capsule, two other McDonnell employees began to play significant roles in man-rating this machinery. The company was fortunate to have its own so-called "astronaut" in the person of Gilbert B. North, another test-pilot engineer but one with a unique relationship for the NASA contract. He was always being confused with his identical twin brother, Warren J. North, who served Silverstein and George M. Low in Washington as NASA Headquarters participant and monitor in astronaut training. Gilbert North served McDonnell as chief human guinea pig in the St. Louis ground tests. Warren and "Bert" North actively promoted the incorporation of test-pilot concerns in the Mercury program from two standpoints outside STG.

Most of the astronauts and test pilots, including the North twins, instinctively resented the "interference" of psychologists and psychiatrists in Project Mercury. Willing to wager their careers and perhaps their necks on the automatic systems of the capsule and booster, the pilots preferred to study the reliability of the machines and to assume themselves adaptable and self-reliant in any situation. They were thus unprepared to discover that psychologists would be among their strongest allies in gaining a more active role for man during Mercury missions. Throughout 1959, arguments over the necessity for the three-axis handcontroller, as opposed to the more traditional two-axis stick and one-axis pedal control system, demonstrated these pilots' confidence in themselves. Distrusting what they regarded as tender-minded psychology and psychiatry, the astronauts-in-training studied hard to become more tough-minded electromechanical engineers. And indeed their first complaints regarding spacecraft design resulted in changes adopted formally during September for later models of the capsule.[54]

John Yardley fortunately was not quite so tough-minded and recognized early an imbalance in detail design considerations. He insisted on having the cross-fertilization of parallel human engineering studies. McDonnell hired in February a "human engineering" expert, Edward R. Jones, to conduct studies of pilot tasks and to analyze the various ways in which the man might fail his machines. Proposing straightaway a thorough training regimen for the astronauts in procedures

simulators, Jones went on to program a statistical computation of the human-factors implications of failures in the automatic systems in the Mercury capsule. By November 1959, Yardley and Jones together had convinced a majority of McDonnell engineers that man should more often be in the automatic loop than out of it.[55]

Part of the problem faced by Jones, Yardley, and the astronauts in regard to human factors and the "inhuman" automatic control systems was the initial position taken by seven members of a study group at the Minneapolis-Honeywell Regulator Company in March 1959. Assigned to recommend approaches to mission analysis and cockpit layout, this group, led by John W. Senders, James Bailey, and Leif Arneson, had reported to McDonnell that since "this vehicle does not behave like an airplane . . . . There is no apparent need for a complex, highly integrated display configuration at a sacrifice of reliability." [56] Jones studied the Minneapolis-Honeywell reports carefully and said they expressed a "wooden man" approach. Assuming pilot safety would be provided for, Jones believed more provisions should be made for the pilot to assure mission success. In August, Jones and a colleague, David T. Grober, wrote for Yardley a description of the quantifiable differences between flying this spacecraft and flying aircraft. They admitted: "Primary control is automatic. *For vehicle operation, man has been added to the system as a redundant component who can assume a number of functions at his discretion dependent upon his diagnosis of the state of the system.* Thus, manual control is secondary." [57] But Jones and Grober pointed to at least eight ways in which automation for reliability could interact with the autonomy of the astronaut to vary the chances both for pilot safety and for mission success. They warned McDonnell's reliability engineers against assuming, as they had in their latest formal reliability program given STG, that the reliability of the astronaut is unity:

> It has been assumed naively by those who are not familiar with the capsule that the operation of the systems will not be difficult because of the automatic programming of the normal mission and because of an assumed simplicity of the systems. However, preliminary analysis indicates that the operation of the capsule, considering the stringent mission requirements and the physiological environment, will be as difficult or probably more difficult than high performance aircraft. A vast number of different potential malfunctions may occur in the capsule's systems, and the isolation of these malfunctions can be extremely difficult. *Mission reliability determinations assume the astronaut can detect and operate these systems without error.*

Only three months later Jones read a paper before the American Rocket Society that, while not a reversal of primary and secondary control modes for the manned satellite, marked a symbolic shift from automation to monitored automatic flight. Man's function in space flight, argued Jones, should now be recognized as something more than secondary, if still less than primary:

> Serious discussions have advocated that man should be anesthetized or tranquillized or rendered passive in some other manner in order that he would not interfere with the operation of the vehicle . . . . As equipment becomes available, a more realistic approach evolves. It is now apparent with the Mercury capsule that man, beyond his scientific role, is an essential component who can add considerably to systems effectiveness when he is given adequate instruments, controls, and is trained. Thus an evolution has occurred . . . with increased emphasis now on the positive contribution the astronaut can make.[58]

Jones spoke, presumably, of the general attitudes prevailing around McDonnell. His fellow psychologist in STG, Robert B. Voas, supported his evaluation.

Nevertheless, until some Mercury missions were flown automatically to qualify the integration of all systems, man would not be allowed to fly one. Of all the critical systems in Mercury, therefore, the automatic controls, a part of which was the "autopilot," were most crucial for man-rating the capsule.

Guidance and control engineers in Project Mercury were often plagued by semantic confusions between the different electromechanical systems they designed and developed to stabilize, guide, control, or adjust relative motion. Their nomenclature helped confound confusion by the similarity of initials in official use to denote their orientation systems: ACS, ASCS, RCS, and RSCS all looked similar to men with other concerns, but some evolutionary reasons help explain the technical differences behind the initials. ACS, for Attitude Control System, applied specifically only to the Big Joe capsule, becoming a generic term in Mercury nomenclature after that launch in September 1959. In its place the redundant designation ASCS, for Attitude (or Automatic) Stabilization and Control System, grew up as a name for the autopilot, an airborne electronic computer that compared inputs of electronic sensory information with any deviation from preset reference points on gyroscopes or with the horizon. Outputs from the autopilot could then command small jets called thrusters to spew out small quantities of hot gas in order to maintain balance in space. These hydrogen peroxide jets, their fuel tanks, plumbing, and valves were called simply the RCS, or Reaction Control System.[59] The last of this quartet of initials, RSCS, requires a more thorough explanation.

In August and September 1959, the stabilization controls and drag-braking drogue chute were proving troublesome, and everyone in STG knew this. Provisions for the astronaut, or "human black box," in the control loop complicated every facet of the system, and yet the pilot had little choice over its operation. Robert G. Chilton, Thomas V. Chambers, and other STG controls engineers reconsidered the several different ways in which the Mercury capsule was being designed to act by chemical reflexes with complete self-control.

From the very beginning of controls design for a manned ballistic satellite, Honeywell had suggested using the same digital electronic system, for simplicity's sake, to control all Mercury flights. But this "simple" equipment was unneces-

sarily complicated for the first flight tests and could cause some unnecessary problems. Also, a direct mechanical linkage to a completely independent, completely redundant reaction control system had been provided to ensure that the pilot could adjust manually and proportionally his capsule's attitude in orbit. But this overweight and oversize manual redundancy, fundamental to the Mercury objective of testing man's capability as a pilot in space, was an exceedingly uneconomical part of the original design.

McDonnell and Honeywell controls engineers moved ahead with their development of the digital system while Chilton wrestled with the problem of raising the efficiency of the thirsty manual proportional thrusters. A wired jumper from the handcontroller to the jets for the ASCS should enable the astronaut to tilt or rotate his craft in its trajectory by electrically switching on and off the tiny solenoid valves that supplied hydrogen peroxide gas to the automatic thruster combustion chambers. Because this "fly-by-wire" system completely circumvented the autopilot, inserting the astronaut's senses and brain in its stead, it was not automatic. Rather, it operated semi-automatically; it would allow the pilot to aid or interfere with the automatic adjustment of rotation around his pitch, roll, and yaw axes. Thus in the autumn of 1959 the automatic attitude control system was already compromised by the addition of the semi-automatic fly-by-wire feature.

But this redundancy still seemed inadequate for mission success. Both McDonnell and STG controls engineers proposed various approaches to other attitude control systems for the Mercury capsule in the spring and summer, but Logan MacMillan resisted all such suggestions, awaiting NASA's formulation of a definite policy for judging the urgency of contract change proposals. Every change would invite inevitable delays, and the long leadtime for a new alternate control system (an AASCS!) made MacMillan, Yardley, and Flesh very skeptical of that approach.[60]

The fresh insight of one of the Canadians in STG's flight controls section, Richard R. Carley, helped Chilton to see the need for a second completely independent rate-command orientation system. Together they wrote a compromise proposal early in July that served as the midwife for a "rate damping" system for stabilization control:

> There is a natural reluctance to relinquish the mechanical linkage to the solenoid valves but the redundant fly-by-wire systems offer mechanical simplification with regard to plumbing and valving hydrogen peroxide so the overall reliability may not change appreciably. In fact, considering the controlability of the capsule as a factor in mission reliability, a net gain should result. Simulation tests indicate that manual control of the capsule attitude during retrograde firing will be a difficult task requiring much practice on the part of the pilot. By changing the command function from acceleration to rate, the task complexity will be greatly reduced and the developmental effort on display and controller characteristics can be reduced accordingly.[61]

Out of interminable meetings and proliferating technical committees, a compromise did finally emerge. Chilton's group, together with J. W. Twombly of McDonnell, worked out the design for a semi-automatic rate augmentation system. By connecting three more wires from the handcontroller to the three pairs of solenoid valves guarding the fuel flow to the manual reaction jets, the designers built a bench version of a rate-command control system that utilized the small rate gyros formerly supplying the references only for cockpit instruments. For the production model, rate command fuel would be taken only from the manual supply tank. By the end of October, Chilton's group and Minneapolis-Honeywell had completed preliminary designs of this rate orientation system, now officially sanctioned as contract change No. 61 and called the "RSCS." But the difficult electrical circuit for its independent rate logic system was only in the breadboard stage: wires had been stretched over the two-dimensional drawings as a preliminary test of the circuit designs.

The manual proportional method of slewing the capsule around required an extravagant use of fuel, but the rate mode relegated the manual to a last-ditch method of attitude control. Now with "rate command," essentially another fly-by-wire system superimposed on the manual reaction controls, the astronaut might control precisely his movements in pitch, yaw, and roll by small spurts of gas that would tip him up or down, right or left, and over on one side or the other. The exact attitude of the capsule at the critical time of retrograde firing could be held by this method, and the slow-roll stabilization of the capsule during reentry also could be accomplished by this system. Thus the quest for reliability led to four different methods of orienting the capsule by the end of 1959. Making both the automatic mode (through fly-by-wire provisions) and the manual mode (through the rate command, or RSCS) redundantly operable gave the astronaut three out of four options.

McDonnell and STG already were working with nine major subcontractors and 667 third-tier vendors, and the effort to man-rate all their products and all these subsystems—indeed each part from tiny diodes to the pressure vessel—required thawing out and refreezing the specification control drawings several times. When at the beginning of October NASA approved the funds for installation of an explosive side-egress hatch, a trapezoidal observation window, and another stabilization and control system, McDonnell engineers had already undertaken these and consequent redesign requirements. This independent advance action was evidence of a more advanced approach to the need for concurrent development and production.[62]

To save weight without sacrificing reliability, the electronic specialists—like all other Mercury design engineers—looked for microminiaturized, solid-state components. But they found less than they hoped. Miniature parts were evolving rapidly into microminiaturized parts, but the latter did not have good reliability records yet. Collins Radio Company, for example, holding the subcontract for

capsule communications equipment, emphasized the conservative use of miniaturized but not superminiaturized components to achieve greater reliability.[63] Since the beginning of the development program the target of an effective capsule launch weight of 2700 pounds had been overshot continuously, primarily because of slight but cumulative increments in electrical circuitry weights. Vendors consistently seemed to underestimate the weights of the parts they supplied. At the beginning of October the effective capsule weight was estimated at 2859 pounds. This seemed likely to grow to 3000 pounds unless firm action was taken. A special coordination meeting in St. Louis at the beginning of October established a weight-reduction diet for the capsule development program and admonished NASA "all along the line to decide how much weight reduction should be sought and what items of capsule equipment should be sacrificed in order to achieve the desired reduction." [64]

At the time STG was considering the RSCS, it was also thinking of eliminating the 17.5-pound drogue parachute in the interest of weightsaving. The "fist-ribbon" drogue stabilizer, six feet in diameter and composed of concentric and radial strips of nylon, was being tested at Edwards Air Force Base and at the El Centro Naval Parachute Test Facility, at subsonic and transonic speeds and at altitudes down from 70,000 feet over the Salton Sea. One of the first canopies, released at a speed of mach 1.08 from an F–104 jet fighter at an altitude above 10 miles, plummeted into denser air whipping, fluttering, and spinning so badly that it disintegrated after a minute of this punishment. This test had put a special premium on development of the rate stabilization control system.

The recent decision to substitute a ring-sail for the extended-skirt main landing parachute made Gilruth fear that there might not be enough experience with big parachutes to determine whether they had similar bad characteristics. Gilruth and Donlan were so unsettled by the chute tests in general that they appealed to Washington for an expansion of applied research programs aimed at the development of more reliable parachute systems:

> It is apparent that the large load cargo type of parachute is far from as reliable as the personnel parachute that most people are familiar with. Part of this lack of reliability is due to unknown scale effects, perhaps. However, it is known that a great deal of this loss of reliability is due to the various fixes that are employed on large parachutes to attenuate the opening shock. Such fixes as extended skirts, slots, reefing, and other devices are designed to cause a parachute to open more slowly. Therefore, it is not surprising that this tendency to open slower is also accompanied by a tendency not to open at all.[65]

Continued tests of the main parachute revealed few additional problems, but the drogue chute tests were getting worse. By the end of September the problem of drogue behavior at relatively high altitudes and barely supersonic speeds was so critical that the director of Langley thought it might be "easier to avoid than to solve." [66] All sorts of alternatives, including a flexible inflatable-wing glider proposed by Francis M. Rogallo of Langley, a string of discs trailing like a Chinese

kite, and simple spherical balloons, were proposed as possible means of avoiding the instability of porous parachute canopies at high altitudes, where the air to inflate them is so rare.

Toward the end of 1959 still another lesson learned from studies of the aerodynamic stability of the capsule in the rarefied upper atmosphere added a slight refinement to the Mercury configuration. To break a possible "freeze" if the stable capsule should reenter the atmosphere small end forward, a spring-loaded destabilizing flap was installed under the escape pylon. Donlan and Purser asked George Low to explain around Washington why this "mousetrap" destabilizing flap was added to the antenna canister and why this innovation would require further wind tunnel tests:

> The Mercury exit configuration (antenna canister forward without escape tower) has been shown to be statically stable at mach numbers greater than four. This stability is undesirable because of the possibility of the capsule reentering the atmosphere antenna canister forward. Tunnel tests at a mach number of six have indicated that a destabilizing flap prevents this undesirable stability region. It is therefore necessary to know the effect of this destabilizing flap at subsonic and supersonic speeds.[67]

Continued poor performance of the fist-ribbon drogue convinced Faget, Chamberlin, and Yardley by the end of 1959 that the drogue chute should be eliminated altogether, but Gilruth and Purser, among others, saw as yet no cheaper insurance and no more workable alternative.[68] The mousetrap destabilization flap and the rate stabilization system would help to fill only the mid-portion of the gap in the reentry flight profile. It was still a long way down from 100,000 to 10,000 feet above sea level—roughly 17 miles as a rock might drop. But by this time, the big questions concerning the first part of the reentry profile had been answered by the Big Joe flight.

## Big Joe Shot

On the same day, September 9, 1959, both the major preliminary flight test of Project Mercury and the final qualification flight test of the operational Atlas ICBM occurred, in separate launches from opposite sides of the United States. While NASA and STG were focusing their attention on the performance of Atlas booster No. 10–D, being launched from Cape Canaveral, most of the men behind the Atlas were watching missile No. 12–D being launched from Vandenberg Air Force Base in California. A novitiate crew of Strategic Air Command (SAC) officers and men had groomed No. 12–D for this critical test flight southwestward over the Pacific Missile Range. Likewise, neophytes from NASA stood by their payload on the Atlas 10–D, awaiting the results of its southeastward flight over the Atlantic Missile Range. If all went well this day, the Atlas would have proved itself capable both as an operational ICBM and as a launch vehicle for a Mercury ballistic flight. Reliability was something else again, but capability could be proved with one demonstration.

The men from Space Technology Laboratories; from Convair/Astronautics; Rocketdyne; General Electric; Pan American, who managed the "housekeeping" of the Atlantic Missile Range; and numerous other contractors supporting the Air Force development of the Atlas, deserved to be called experts. They had had experience in launching this rocket. By contrast, NASA personnel were even greener than the SAC crew going through the countdown at Vandenberg. NASA did not intend to learn to launch its own Atlases, but STG did hope to gain some expertise for living through its launches. The job of launching Big Joe belonged to the Air Force, supported by the Convair/Astronautics team at the Cape—Byron G. McNabb, Travis L. Maloy, Thomas J. O'Malley, C. A. Johnston, and others. Charles Mathews, the STG mission director, learned much about his operational requirements working with these men on Big Joe.

Few people outside the military-industrial teams working on the Atlas could have known what was happening in the ICBM program in mid-1959.[69] The fourth and supposedly standard version of the Atlas ICBM, designated the Atlas D, rapidly supplanted the third development version, called Atlas C, during the summer of 1959. Earlier A and B models, fired in 1957 and 1958, had phased through C and into D concurrently. The Air Force had committed itself in December 1958 to supply NASA with standard Atlas Ds for all Mercury missions. The first installment on this commitment came due in September, at the same time that the weapon system was to prove itself operational. Since April 14, 1959, when the first series-D missile exploded 30 seconds after liftoff, only four other Atlas Ds had been launched, the second and third of which were partial failures or partial successes, depending upon one's point of view.[70]

In July and August, however, the two successful Atlas-D launchings were supplemented by exceptionally encouraging flights of the last two series-C Atlases. Atlas 8–C had flown on July 21, bearing "RVX–2," or the first ablative reentry nose cone adapted to the Atlas. It was especially welcome to STG officials; both the flight and the recovery provided demonstrative evidence to reinforce STG's commitment to the ablation principle for the Mercury heatshield.[71]

Joe is a common name, but there was nothing common about the big Atlas missile and the Mercury payload that stood poised upright at launch complex 14 at Cape Canaveral on September 9, 1959. Some had hoped that Big Joe would skyrocket on July 4, but the launch date was postponed until mid-August by the Air Force because the booster did not check out perfectly at first. Then it was put off until early September by STG engineers, who were stymied by troubles in the sophisticated instrumentation and telemetry. Finally, on the evening of September 8, Atlas 10–D, the sixth of this model to be flight tested, stood on its launch pad at Cape Canaveral with a replica of the Mercury capsule (minus an escape tower) at its tip. All NASA waited for the countdown to begin at midnight. About a fourth of the Space Task Group members were at the Cape for the "Atlas ablation test." From this first full-scale, full-throttle simulation of the reentry problem, every member could expect further task definitions.

If Atlas 10–D should fail, if the boilerplate capsule should fail its test or be lost, then a backup shot, Big Joe II, would have to be made. But without proof that the ablation heatshield could actually protect a man from the intense frictional heat of reentry, and without dynamic evidence that the frustum-shaped spacecraft would actually align itself blunt-end-forward as it pierced the atmosphere, all the rest of the "R and D" invested in Faget's plan would avail little.[72]

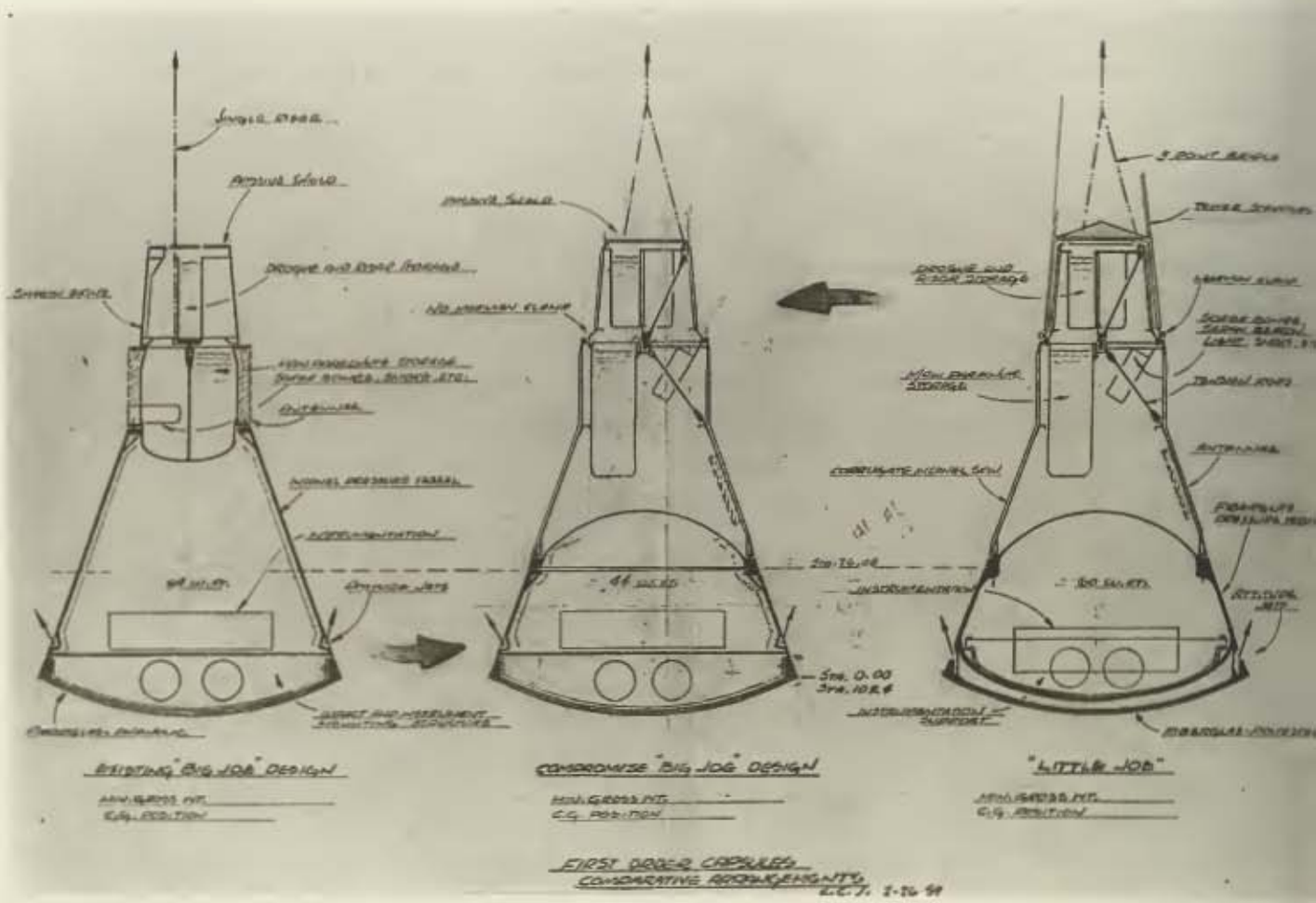
The nose-cone-capsule for Big Joe, handcrafted by NASA machinists, had no retrorocket package. The inner structure held only a half-size instrumented pressure vessel instead of a pressurized cabin contoured to the outer configuration. Built in two segments, the lower half by Lewis and the upper by Langley craftsmen, the main body of the spacecraft replica was fabricated of such relatively thin sheets of corrugated Inconel alloy in monocoque construction that the appellation "boilerplate" capsule was especially ironic.[73]

For this model of the Mercury payload, more than a hundred thermocouples were installed around the capsule skin to register temperatures inside and under the heatshield, sides, and afterbody. Jacob Moser and a group of instrumentation specialists from Lewis had developed a multiplex system for transmitting data over a single telemetry link from all thermocouples plus 50 other instruments, including microphones, pressure gauges, and accelerometers.

Back in Cleveland, three controls engineers, Harold Gold, Robert R. Miller, and H. Warren Plohr, had designed a "cold-gas" attitude control system, using high-pressure nitrogen for fuel. They had worked directly with Minneapolis-Honeywell to devise the gyros, logic, and thrusters for the critical about-face maneuver after separation. It was essentially unique in its use of cold-gas nitrogen thrusters rather than the "hot-gas" hydrogen peroxide systems that Bell Aerosystems had developed for the X–15 program.[74]

To STG novices watching the launch preparations, the Atlas and the organization of people it required to get off the ground seemed incredibly complex. But they themselves were not well organized even for their sole responsibility with the payload. Big Joe had three bosses, all at work under Mathews. Aleck C. Bond, the Langley heat-transfer specialist, had accepted from Faget almost a year ago the responsibility for the overall mission success. B. Porter Brown, the Langley engineer first sent to pave the way for STG at the Cape, acted as STG's chief liaison with the Air Force-Convair team. And Scott H. Simpkinson, leading the group of about 45 test-operations people from Lewis, had been living with the capsule for Big Joe in a corner of Hangar S since the second week in June, when checkout and preflight operations tests began. The NASA-Goddard crew still held most of the hangar space in preparation for *Vanguard III,* their culminating launch, scheduled later in September.[75]

Porter Brown bore the title of NASA Atlas-Mercury Test Coordinator and worked—along with NASA Headquarters representative Melvin Gough—under nominal direction from the Missile Test Center. To fathom the complexity of launch operations and organizations at the Cape required expertise, tact, and




*Sketches by C. C. Johnson of comparative boilerplate Mercury capsules used in Big Joe and Little Joe test flights. The sketches, dated February 26, 1959, show the transition from the original Big Joe capsule design (left) to the one actually used (center), which in turn would be a precursor of the capsules used in Little Joe launches.*

drive. Security restrictions were so strict for the Atlas, and agencies and launch crews so compartmentalized, that horizontal or interpersonal communications in the lower echelons were virtually nonexistent. Brown had to keep vertical communications open and establish STG's "need-to-know" at every step.[76]

To launch a missile required a stack of documents almost as tall as a gantry. Documents called "preliminary requirements," "operations requirements," "operations directives," "test directives," and innumerable other coordinating catalogs had to be circulated and their orders followed before, during, and after getting a rocket off the ground. To active young engineers with a mission, this paperwork could only be frustrating, but Air Force experience had shown the value of the documentation system in imposing order on a chaotic situation.[77]

Atlas 10–D was programmed to rise, pitch over horizontally to the Atlantic before it reached its 100-mile peak altitude, then pitch down slightly before releasing its corrugated nose cone at a shallow angle barely below the horizontal.

In the near vacuum of space at that altitude, tiny automatic thrusters in the capsule should make it turn around for a shallow reentry into the stratosphere. The friction of the air, gradually braking the speed of the descent, would dissipate the kinetic energy imparted to the capsule by the Atlas. An incandescent cauldron of this transformed energy would envelop the capsule like a crucible as it penetrated denser air. It was hoped that enough of this heat would be deflected by the slip stream and boiled away into the turbulent boundary layer of the shock-wave to protect the capsule from vaporization. This flight should simulate closely what a man must ride through if he was to live to talk about an Atlas-boosted, Mercury-returned orbital flight around Earth.

About 2:30 a.m., a 19-minute hold in the countdown was called to investigate a peculiar indication from the Burroughs computer that was to guide the launch. A malfunction was found in the Azusa impact prediction beacon, a transponder in the booster. Since there were several redundant means, including an IBM machine that was part of the range safety system, for predicting the impact point, the trouble was ignored, the countdown resumed, and liftoff occurred at 3:19 a.m.[78]

It was a beautiful launch. The night sky lit up and the beach trembled with the roar of the Rocketdyne engines. For the first two minutes everyone was elated. Then suddenly oscillograph traces indicated that the two outboard booster engines had not separated from the centerline sustainer engine, as they were supposed to do when their fuel was exhausted. Flight controllers and test conductors in the blockhouse and control center began to worry about "BECO" (or booster engine cutoff) as contradictory signals appeared on their panels and computer readout rolls. Apparently all systems within the capsule were performing as planned, but the capsule seemed not to do its half-somersault. The added weight of the booster engines retarded velocity by 3000 feet per second. The Burroughs computer predicted an impact point about 500 miles short. All eight reaction control jets seemed to be working perfectly, yet the reentry attitude could not be verified before the telemetry blackout occurred as the capsule skidded back into the atmosphere.[79] No one could ascertain what had happened during that 20-minute flight unless the recovery forces downrange could retrieve the capsule and its onboard tape recordings.

Six ships of Destroyer Flotilla Four began racing uprange at flank speed. Patrol and tracking planes started flying their search patterns. Before dawn, tracking ships and downrange tracking stations detected the sofar bomb explosion underwater, and provided new coordinates for the point of impact. As the sun rose over the sea, a Navy P2V Neptune patrol plane, homing in on a sarah beacon signal, reported sighting the capsule bobbing in the water. It vectored the nearest destroyer, now still over 100 miles away, to the green-dyed area for retrieval. It was still too early to tell whether the primary objectives of Big Joe had been achieved. But as the morning progressed, more evidence from the range made it appear that all telemetry had functioned properly. If the capsule could be

recovered before it sank, the most important objective, finding out how well the capsule's ablation shield had endured reentry, could be evaluated quickly.

While eager newsmen at the Cape were being cautioned to avoid erroneously identifying this custom-built prototype as the Mercury capsule, technicians were busily analyzing "quick-look" data that would give more information about booster and payload separation performance, the attitude control system, the internal and external temperature history of the model, noise and vibration levels, telemetry and tracking effectiveness, and acceleration and deceleration peaks.

About seven hours after launch, exultation swept over the Big Joe launch team at the Cape when the destroyer *Strong* reported that she had netted the precious capsule intact and secured it on deck. The terrestrial return trip by water and air required another 12 hours. As soon as the transferring cargo plane arrived at Patrick Air Force Base, the capsule was loaded onto a dolly, and a police escort cleared the way for the shrouded trailer bearing the tangible remains of the Big Joe mission along the 15 miles through Cocoa Beach to Cape Canaveral.

When the capsule arrived back home in Hangar S, about midnight, every NASA person at the launch site that day gathered around the capsule for a joyous autopsy. Gilruth, Faget, Mathews, Bond, Brown, and Simpkinson stood by as someone dropped the canvas veiling the secret heatshield. The group marveled at the superb condition of their archtype. Bond ran his fingers over the now cool glass beads on the face of the ablation shield, noticed that the afterbody was barely singed. Brown scratched the white-paint legend "United States" and found it hardly discolored. Although one of the afterbody recovery eyes was welded shut by reentry heating, a piece of masking tape, which Simpkinson had allowed to remain, was still intact inside the outer conical shell. A tired but happy crew unscrewed the two halves of the inner pressure vessel and handed to Gilruth a letter that had been sealed inside and signed by 53 people under Mathews in anticipation of this occasion:

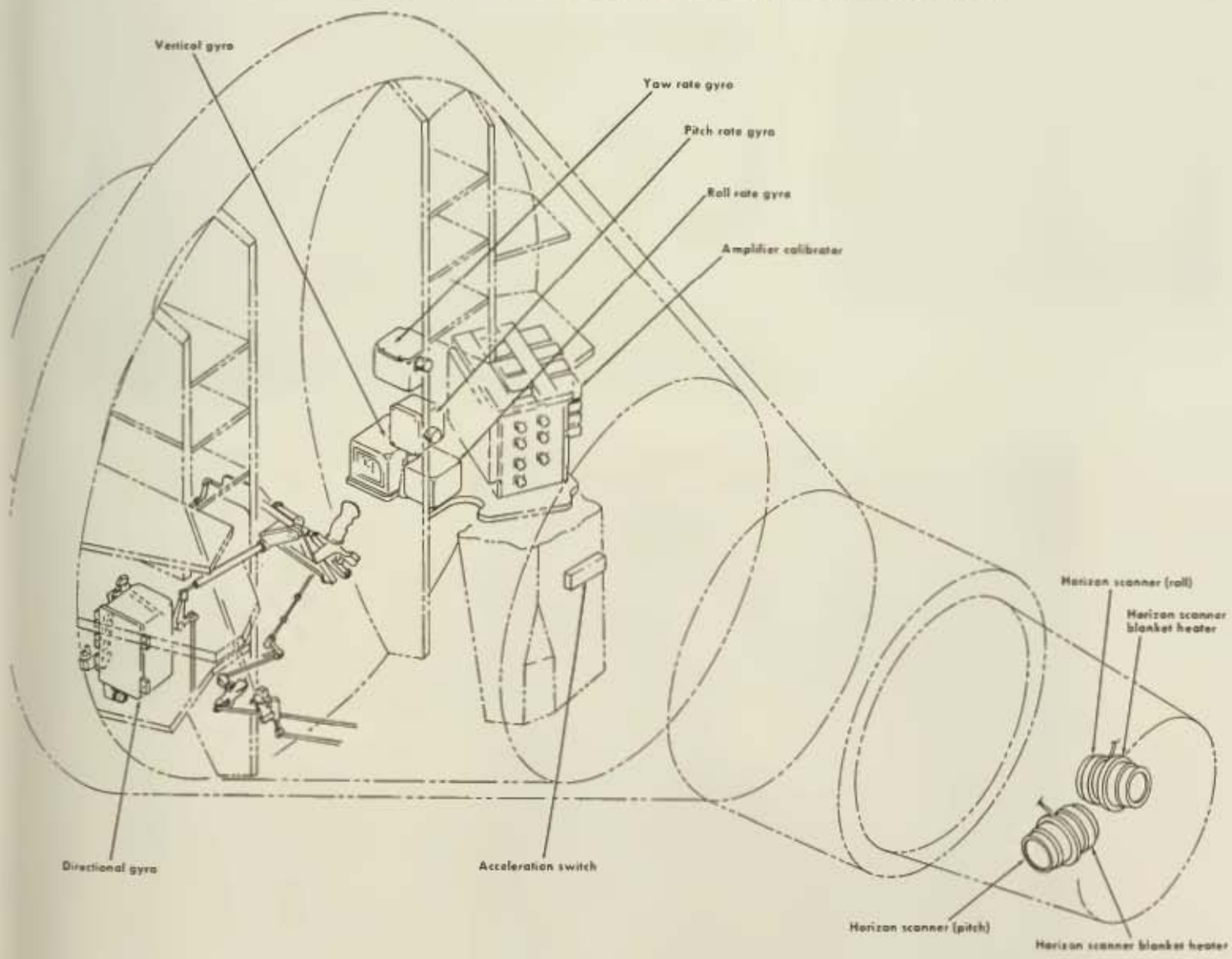
> This note comes to you after being transported into space during the successful flight of the "Big Joe" capsule, the first full-scale flight operation associated with Project Mercury. The people who have worked on this project hereby send you greetings and congratulations.[80]

Within a week, data reduction made possible the reconstruction of the inflight history of Big Joe. As suspected, the outboard engines had failed to stage after booster engine cutoff, and the additional weight degraded the Atlas velocity about 3000 feet per second. This meant the trajectory of the flight path had been steeper and slightly lower than planned and that the sustainer engine had powered the capsule into a steeper downward course before burnout. Without a positive force to divide the two objects in free fall, the capsule had separated from the booster about 138 seconds late, after all of its high-pressure nitrogen fuel was expended in trying futilely to turn both booster and spacecraft around for reentry. When it finally broke loose from the launch vehicle at an altitude

of 345,000 feet and at a space-fixed speed of almost 15,000 miles per hour, the capsule was an exhausted, passive, free-falling body. Yet by virtue of its configuration and center of gravity, the capsule turned itself around without the aid of either thrusters or damping controls and reentered the atmosphere successfully. The dynamic stability of the capsule configuration was so good that doubt of its ability to damp out its entry oscillations was also ended.

The heat pulse sustained in the actual Big Joe trajectory was shorter but considerably more severe than planned. If STG had been testing a beryllium heat sink shield, these untoward conditions would not have proved anything. For the ablation heatshield, the length of the heat pulse was sufficient to prove the value of the approach. The sequencing, structures, instrumentation, and cooling system had all worked well. The recovery of the capsule inspired so much confidence among STG leaders that Big Joe II, the backup launch, was canceled within three weeks.

*The Mercury capsule Automatic Stabilization and Control System.*



Cores and slices taken from the conservatively designed heatshield at many locations proved that the heating was uniform over its face and that its structural integrity had survived impact without compromise. The depth of ablation charring was shallow enough to leave at least two-thirds of the fiber-glass material in pristine condition. Bond and Andre J. Meyer were especially pleased with the large margin for error represented by the thickness of the heatshield remaining. Subsequently, they were able to reduce the thickness and the weight of the shield by almost one half.

One note of caution remained in all the jubilation following Big Joe. Leonard Rabb, the head of Faget's theoretical heat transfer section, signed a memo on October 7 demanding action to prove that the short heat pulse on Big Joe could be disregarded. "Calculations indicate," said Rabb, "that the present Mercury heatshield will *not* survive a reentry due to natural decay." If retrorockets should be lost or become inoperative and if the ablation shield in orbit should have to sustain and dissipate the long, slow building of the heat pulse over 24 hours or so, catastrophe would result, Rabb warned:

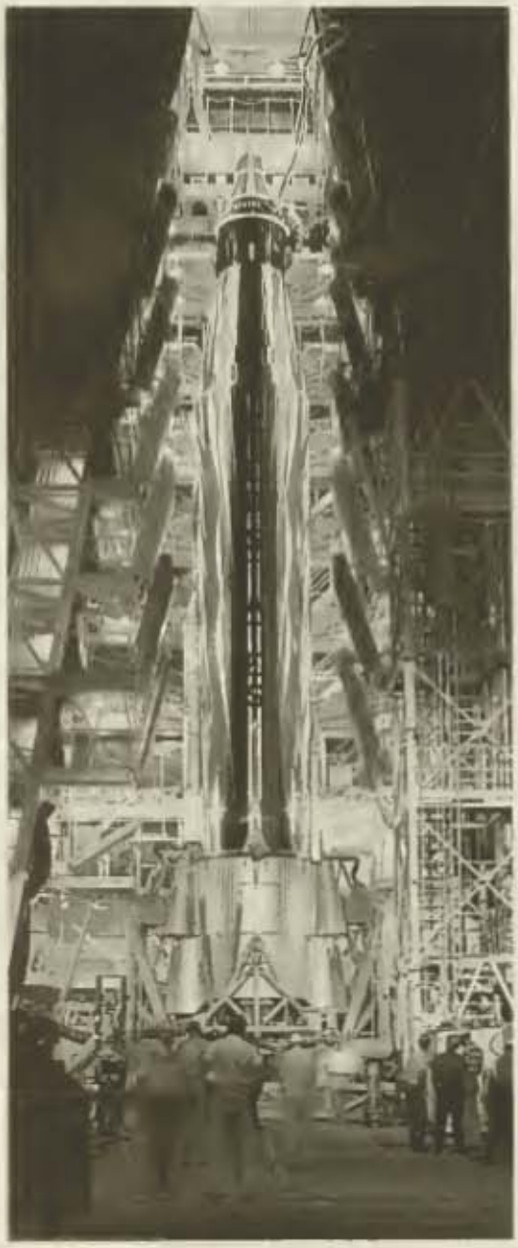
> Under no circumstances should the weight of the heat shield itself be shaved. Recent calculations cast doubt on the shield's performance, not only for natural decay reentry but for the one retro [rocket instead of three or two] case as well.[81]

By the end of October, the working papers giving the results of Big Joe were published, and gradually the lessons learned from this shot were incorporated in a number of major redesign decisions. The features that became standard for Project Mercury as a result of Big Joe have been summarized by Aleck Bond:

> (1) In view of the excellent performance of the ablation shield, the back-up beryllium heat sink shield was dropped from further consideration for Mercury orbital missions.
> (2) The basic heat shield fabrication techniques employed for the Big Joe shield were adopted for the Mercury heat shield.
> (3) The detailed temperature measurements made on the Big Joe shield provided for an efficient design thickness for the Mercury shield.
> (4) The afterbody heat transfer measurements indicated a need for heavier external thermal protection than had been provided for the Mercury spacecraft, and as a result the shingles on the conical afterbody were thickened and on the cylindrical afterbody the original René shingles were replaced with the thick beryllium shingles in order to handle the high heating loads in this region.
>
> * * *
>
> The ability of the spacecraft to survive the severe test of reentry from near-orbital velocities in spite of its unprecedented release conditions, is certainly worthy of note. The heat shield performance was excellent and the results indicated that the original design concepts were sound. The spacecraft performance as a freebody reentry vehicle was exceptional. An important characteristic of the Mercury design was demonstrated; that the spacecraft could

## Big Joe
## Sept. 9, 1959

*Big Joe was a critical flight in Mercury, combining a test of the reentry concept employing the ablating heatshield and a test of the as yet only half-tested launch vehicle, the Atlas D. At right, Big Joe on the launch pad at Cape Canaveral, being groomed for the big event. Below, Aleck C. Bond (left), Big Joe project engineer, and Scott H. Simpkinson, who had been in charge of capsule checkout at the Cape, kept track of their charge during the flight. Below right, the slightly singed but gloriously intact Big Joe capsule after its retrieval from the Atlantic.*







reenter the atmosphere at high angles of attack and maintain the heat shield forward attitude without the aid of a control system! [82]

The elation of the Task Group over the dynamic proof of its passive design of Mercury was not shared by the Atlas people. Their booster 10–D, having failed to stage, performed only marginally and in fact was classed a failure by the Air Force and STL. But across the country, on the Pacific Coast, Atlas 12–D, launched by the SAC crew under the tutelage of Convair/Astronautics and STL, performed as a true ICBM on a 5200-mile flight to its target in the South Pacific. Immediately thereafter the Air Force announced the Atlas was now operational. Apparently the force-in-being totaled only the two missiles erected in training gantries at Vandenberg, but the delicate balance of power could not wait for the buildup of numbers.[83]

## Little Joe Series

While the results of the Big Joe launch were being studied, a five-man investigating committee at Langley was trying to learn why the first Little Joe shot, on August 21, 1959, had miscarried so badly. Out at Wallops Island that Friday morning several weeks earlier, the first Little Joe (LJ–1) had sat on its launcher, tilted toward the sea, with a full-sized model capsule and escape system on top. Its test mission was to determine how well the escape rocket would function under the most severe dynamic loading conditions anticipated during a Mercury-Atlas launching. At 35 minutes before launch, evacuation of the area had been proceeding on schedule, and the batteries for the programmer and destruct system in the test booster were being charged. Suddenly, half an hour before launchtime, an explosive flash and roar startled several photographers and crewmen into diving for cover.

No one was injured, but when the smoke cleared it was evident that only the capsule-and-tower combination had been launched, on a trajectory similar to an off-the-pad abort. The booster and adapter-clamp ring remained intact on the launcher. Near apogee, at about 2000 feet, the clamping ring that held tower to capsule released and the little pyro-rocket for jettisoning the tower fired.[84]

The accident report on LJ–1, issued on September 18, blamed the premature firing of the Grand Central escape rocket on an electrical leak, or what missile engineers were calling "transients," "ghost" voltages or currents, or simply a "glitch" in a relay circuit. The fault was found in a coil. It had been specially designed as a positive redundancy to protect biological specimens from too rapid an abort and as a negative redundancy to prevent inadvertent destruction of the test booster. Again the problem of upgrading the machines to provide safety for animal payloads as well as to ensure mission success had created unexpected problems. This first trial of the brand-new Little Joe test booster apparently had been too ambitious. Fortunately the momentum of the Little Joe test series was not disturbed by the debacle of the boilerplate payload on Little Joe No. 1.

North American Aviation finished and shipped on September 25, 1959, its sixth and last airframe for the Little Joe booster as promised. The Space Task Group therefore had available at the beginning of October all the Little Joe test boosters it had ordered. Designed primarily to man-rate the escape system operating from a Mercury-Atlas already in flight, the Little Joe booster also was committed to perform some biological research before fulfilling its primary mission.[85]

More by coincidence than by design, the next three Little Joe boosters were launched from Wallops Island exactly one month apart in the autumn of 1959. Still the primary aerodynamic test objectives remained unfulfilled. But the fourth shot, in January 1960, finally worked precisely as planned. STG was satisfied that its own pilot safety provisions were viable under the worst possible aerodynamic conditions. The same kind of test on McDonnell's finished product, rather than on boilerplate demonstration capsules, perhaps could be made the following summer.

On October 4, 1959, the same booster that had been jilted by the capsule and escape rocket in August was finally fired, this time with a double dummy—an uninstrumented boilerplate model fitted with an inert escape rocket system. After the fiasco of LJ–1, the more modest purpose of this test, which later became known as Little Joe 6 (LJ–6), was to prove the "reliability" of the whole booster propulsion cluster. All four Pollux motors, plus four smaller Recruit motors, were set to fire in sequence. Little Joe 6, 55 feet tall and weighing 20 tons at liftoff, blasted up to a peak altitude barely short of 40 miles; then it was intentionally destroyed after two and a half minutes of flight to prove the destruct system. Impact was over 70 miles from Wallops Island. All went well.[86]

Satisfied that Little Joe had proved itself as a booster, the supervisory team of NASA engineers, consisting of John C. Palmer from Wallops, and Roland English, James Mayo, Clifford Nelson, Charles McFall of Langley, and William M. Bland and Robert O. Piland of the Space Task Group, prepared for a new effort to check the correct operation of the abort escape system at maximum loading conditions. The region called "max q" (for maximum dynamic pressure) by aerodynamicists is the portion of the flight path at which relative speed between the vehicle and the atmosphere produces the greatest air resistance on the vehicle. Many variables were involved, but roughly both Little Joe and the Mercury-Atlas were expected to experience dynamic pressures of almost 1000 pounds per square foot at an approximate altitude of six miles after about one minute of flight time.

For the second attempt at this primary mission, Little Joe 1–A (LJ–1A) needed to propel another dummy capsule and pylon to the max q region. Both drogue and main parachute behavior were to be carefully studied on this flight. Surprised by the insistent demands from the news media to witness these developmental flight tests, STG gave the press a careful enumeration of situations that might call for a "hold" or a "scratch" of the shot.[87]

On November 4, 1959, when the second Little Joe booster was successfully launched, newspapermen could see nothing wrong. The flight looked straight and

true until the rocket was out of sight. But the test engineers in the control center observed that the escape motor did not fire until 10 seconds after the point of maximum dynamic pressure. The parachutes and recovery operations performed well enough to fulfill secondary and tertiary objectives, but precisely why escape was too slow was never fully understood. Later analysis showed only that the delayed ignition of the escape rocket caused the separation of capsule from booster at a pressure only one-tenth of that programmed.[88] Because the next scheduled launch of a Little Joe booster was already committed to a test for certain aeromedical objectives and was now in a late stage of preparation, the primary aerodynamic test of the escape system was postponed until January, when a third try, to be called Little Joe 1–B, could be made.

Back in May, STG had begun planning with the Air Force School of Aviation Medicine to include some biological packages in later Little Joe flights. The booster designated No. 5 was reserved specifically to qualify all systems in the McDonnell capsule, carrying a chimpanzee occupant and escaping from a simulated Atlas explosion at the point of max q.[89]

After the disappointment of Little Joe 1–A, Donlan, Bland, and Piland decided to pull out the stops on Little Joe 2 and allow the aeromedical specialists to run all the experiments they wanted on a high-powered flight. The School of Aviation Medicine had made ready a biological package for its primate passenger, a small rhesus monkey named "Sam," after his alma mater. In addition to Sam's special capsule for rocket flight, the military physicians now prepared barley seeds, rat nerve cells, neurospora, tissue cultures, and insect packets to measure the effects of primary radiation, changes in appearance and capacity for reproduction, and ova and larvae responses to the space environment.

Little Joe 2 promised to be a spectacular flight if everything went as planned. The engineers could see how the capsule escape system would function under conditions of high mach number and low dynamic pressure; more important technically, they could measure the motions, aerodynamic loads, and aerodynamic heating experience of the capsule entering from the intermediate height of about 70 miles. The Air Force medical specialists might also learn about other things, but their chief interest was to see how well Sam himself would withstand weightlessness during the trip. This was also the chief interest of Alan B. Shepard and Virgil I. Grissom, who came to see this launch.[90]

On December 4, 1959, just before noon, the third Little Joe, LJ–2, ripped through the air under full power and burned out at an altitude of 100,000 feet. The tower and capsule separated as planned and the escape rocket gave an additional boost, throwing the capsule into a coasting trajectory that reached its zenith just short of 280,000 feet, or 53 miles. This peak height was about 100,000 feet lower than expected because of a serious windage error, so Sam experienced only three minutes of weightlessness instead of four. He survived the mild reentry, the not-so-mild impact, and six hours of confinement before he was recovered by a destroyer and liberated from his inner envelope.[91]



**Little Joe 2**
**Dec. 4, 1959**

*A launch from Wallops Island was a quieter, simpler affair than at the Cape. This photo of LJ–2 being readied for launch shows the unpretentious gantry and service structure. The live payload for the flight, Sam, the rhesus monkey, is shown before the flight strapped into his miniature replica of the Mercury astronaut couch.*



All preliminary indications reflected a highly successful flight. For the first time Little Joe had achieved full success on all three orders of its programmed test objectives. Congratulatory letters sped around the circuit among those responsible. It was a satisfying way to close out the year. But STG engineers knew that this full-performance test of the Little Joe was not the most crucial case for man-rating the Mercury escape system. They still had to prove that at max q, where everything conspired to produce failure, the escape system could be relied upon to save the life of any man who ventured into this region aboard an Atlas.

Later evaluations of Little Joe 2 were somewhat less sanguine. Biologists were disappointed: although results were better than on any previous biological space flight, they were still not good enough. STG engineers still awaited the more crucial test of the escape system under maximum aerodynamic stress. And the Mercury managers were disappointed at the way the news media had dramatized the animal experiments at the expense of the equally significant demonstration of technological progress.[92]

Public information officers John A. Powers of STG and E. Harry Kolcum of NASA Headquarters tried to correct the "misplaced emphasis" in the news stories before the fourth Little Joe shot, Little Joe 1–B, occurred in January. By this time, Gilruth wished the press would note "the relatively minor role of this particular task in the context of the total Mercury program."[93] But again, to the reporters the star of the event was "Miss Sam," the female counterpart to the occupant of LJ–2, whose life was at stake and whose nervous system was to be tested in psychomotor performance tasks during the short but severe flight. Some of the newsmen perhaps knew or divined that several of the astronauts wanted to ride one of the next Little Joes into space.

Finally, on January 21, 1960, with the fourth launching of the Little Joe series, the escape system performed as planned at the point of max q.[94] Propelled by two Pollux main motors, Little Joe 1–B blasted up to the nominal altitude of slightly less than nine miles and attained a maximum velocity slightly over 2000 miles per hour. Then the escape rocket kicked on the overdrive for an additional 250 feet in one second to "rescue" the Mercury replica from a simulated booster failure at that point. Over a range of 11.5 miles out to sea, Miss Sam, in her biopack prepared by medical technicians from Brooks Air Force Base and its School of Aviation Medicine, not only survived these severe g loads but also performed well (except for a 30-second lapse) at her business of watching for the light and pulling the lever. After 8.5 minutes of flight, during which the sequence system and capsule landing systems worked perfectly, Miss Sam touched down. She was recovered almost immediately by a Marine helicopter, and was returned in excellent condition to Wallops Station within 45 minutes after liftoff.[95]

For half a minute after the escape rocket fired, the little rhesus monkey had been badly shaken up and did not respond to stimuli, but otherwise Miss Sam acted the role of the perfectly trained primate automaton throughout the flight.

Evidence of nystagmus after escape rocket firing and after impact on the water did cause concern, for it suggested that an astronaut's effectiveness as a backup to the parachute system might be impaired. The internal noise level proved to be higher than expected, likewise causing some other worries over the provisions for communications and pilot comfort.[96]

To this point, the Little Joe series of five actual and attempted flights had expended four of the six test boosters North American had made for NASA and five prototype capsules made in the Langley shops. The primary test objectives for these solid-fuel-boosted models were an integral part of the development flight program conducted within NASA by the Space Task Group, with Langley and Wallops support. Now only two Little Joe boosters remained for the qualification flight tests. North American had manufactured seven Little Joe airframes, but one of these had been retained at the plant in Downey, California, for static loading tests. STG ordered the refurbishment of this seventh airframe so as to have three Little Joe boosters for the qualification flight program. The success of Little Joe 1–B in January 1960 meant that the next flight, the sixth, to be known as LJ–5, would be the first to fly a real Mercury capsule from the McDonnell production line.[97] In passing from development flight tests with boilerplate models to qualification flight tests with the "real McDonnell" capsule, the Space Task Group moved further away from research into development and toward operations.

## One World Network

From the beginning of 1959, the United States' first manned space flight program was committed to manned ballistic suborbital flights as prerequisite to a manned orbital flight, and to a world-wide tracking and communications network as a safeguard for its man in orbit. Both of these distinguishing features were means of man-rating its machines. The second began to be implemented only in the latter half of 1959, after NASA Headquarters had relieved STG of the burden of the network.

Neither suborbital flight nor the tracking network for Mercury was established with any real notion of what the Soviets were doing toward a manned space flight program. But that the Soviets were doing something toward this end was made perfectly clear by Premier Nikita Khrushchev during his autumn tour of the United States. Having presented President Eisenhower with a medallion of the Soviet coat-of-arms borne by *Lunik II,* the first manmade object to hit the Moon, Khrushchev visited Hollywood, Iowa cornfields, and the Presidential retreat at Camp David. His departure coincided with press announcements that Soviet pilots were training for an assault on the cosmos. The first pictures of the back of the Moon, made by *Lunik III* on October 4, demonstrated impressive Soviet sophistication in guidance, control, and telemetry, if not in photography.[98]

If various American government agencies late in 1959 knew more than the public did about the probable speed and direction of the Soviet manned space

program, this information was not passed down to the Space Task Group. Top administrators in Washington were undoubtedly accorded "need-to-know" briefings on Soviet progress, but at the working level around STG at Langley there was no such privileged information on the so-called "space race." In fact, not until mid-December did STG learn some of the operational details of Air Force programs then being conducted on the West Coast. Even the Dyna-Soar program, so heavily influenced by Hartley A. Soulé, John W. Becker, and others at Langley, seemed at times to be out of reach to Mercury engineers.[99]

In the "spirit of Camp David" the seven astronauts themselves proposed an exchange of visits and information with their Soviet counterparts, but to no avail. Proof that the United States and the Soviet Union could agree was shown in the Antarctic Treaty signed by 12 nations, including the two giants, on December 1, 1959. In the same spirit only a week later the NASA Administrator offered the services of the Mercury tracking network in support of any manned space flight the U.S.S.R. might care to undertake, but this offer also was stillborn. So sparse seemed available official information on Soviet manned space plans that Paul Purser, as special assistant to Gilruth, assumed an extra duty by beginning a scrapbook of published accounts relating to Soviet manned space flight plans.[100] It would have been "nice to know" in more detail what the Soviets were planning and how well they were proceeding, but STG's "need to know" was mainly psychological curiosity. Such information, if available, probably would have made little difference to the technological momentum of Project Mercury at the end of 1959. The impetus generated for the project by that time was truly formidable and still accelerating.

NASA Headquarters had relieved STG of developing the global range network in the spring of 1959, believing that the Tracking and Ground Instrumentation Unit (TAGIU) at Langley and the communications center at Goddard Space Flight Center together could develop radar and radio facilities more expeditiously. The wisdom of this assignment would prove itself; the communications network was never a cause for delay in Mercury operational schedules.

The decision to build an extensive new tracking network girdling the globe had derived largely from Langley studies of operational tracking requirements made by Edmond C. Buckley, Charles Mathews, Howard C. Kyle, Harry H. Ricker, and Clifford H. Nelson in the summer of 1958. Then followed four extensive and independent studies by Massachusetts Institute of Technology, Ford, Space Electronics, and Radio Corporation of America in the spring of 1959. Many interrelated technical, operational, and diplomatic considerations were involved in the evolution of the network, with pilot safety and limited capsule battery power setting the first standards.

Next to manufacturing the capsule itself, the Mercury network was the most expensive part of the entire program. But that network represented a capital investment in tracking and communications ability that NASA would also use effectively for scientific satellites and space probes. The full compass of the

tracking range and communications network built for Project Mercury is beyond the scope of this volume, but salient features of the chain of tracking stations, of the communications grid, and of the ground instrumentation planned for Mercury set other basic parameters for the project. Hartley A. Soulé, the aeronautical scientist who directed Langley's part of the establishment, made a circumnavigation of the Earth to prepare the circumferential path for orbital overflights.[101]

When Christopher Kraft spoke to the Society of Experimental Test Pilots on October 9, 1959, he explained certain of the major criteria used to choose the orbital plane for Mercury and to select ground stations to monitor the man in orbit. "Since the first manned orbital flight will be a new type of operation involving many new experiences," Kraft said, "it would be desirable to keep the time in orbit as short as practical, while at the same time making an orbital flight." Emphasizing the necessity to secure an accurate and almost instantaneous determination of the potential orbit before actual insertion, as well as an exact retrofiring point and thereby a low-dispersion "footprint," or recovery area, Kraft explained how the first manned orbital mission should shoot for three rather than one or two orbits. He also listed four specific reasons why the best orbit inclination to the equatorial plane would be 32.5 degrees and the most desirable launching azimuth, or direction, would be 73 degrees true: (1) maximum use should be made of existing tracking stations and communications facilities; (2) the Atlantic Missile Range should be used for both the launching and the planned recovery area; (3) the orbital track should pass directly over the continental United States as much as possible to maximize unbroken tracking, especially during reentry; and (4) the orbital path should be planned to remain over friendly territory and temperate climatic zones.[102]

These criteria constrained the choice of both Mercury's orbital plane and its launching azimuth. East-northeast was an unusual firing direction from Cape Canaveral, where ballistic missiles were normally shot southeastward down the Atlantic range. Taking the sinusoidal track displaced for each orbit as it would look on a Mercator world projection, Soulé, Francis B. Smith, and G. Barry Graves of Langley, Mathews, Kraft, and Kyle in STG, and many others resolved the complex trades between the Atlas booster characteristics, capsule weight limitations, launch safety considerations, suitable recovery areas, existing Defense Department tracking and communications networks, and available land for locating instrument stations. Soulé and his Tracking Unit at Langley shouldered most of the responsibility for the compromises between what should and could be done with electronic communications and telemetry to promote pilot safety and ensure mission success.

While STG delegated such decisions as whether to select sites in Kenya or Guadalcanal, where to use C- or S-band radars, and whether to lay a cable or build a redundant control center on Bermuda, it kept tight control on all matters affecting control of the missions and especially of the decisions on orbital param-

eters. John Mayer and Carl Huss, leading STG's Mission Analysis Branch, had learned their celestial mechanics from the traditions established by Johannes Kepler, Sir Isaac Newton, and Forest R. Moulton, but from 1957 through 1959 more and more data from various artificial satellites continually refined their calculations. Keeping in close touch with STL on the improving Atlas performance characteristics, Mayer's group sought to establish the ideal "launch window" or orbital insertion conditions. Not until May 1960 were these parameters established.[103]

John D. Hodge, another Anglo-Canadian, who helped Mathews learn how the Defense Department launching and tracking teams operated at the Atlantic and the Pacific missile ranges, explained how the major compromise on man-rating the worldwide network was achieved in 1959. Physicians like Lieutenant Colonel David G. Simons, of Project Manhigh fame; Major Stanley C. White, on loan to STG from the Air Force; and Colonel George M. Knauf, the staff surgeon at the Air Force Missile Test Center, had argued for continuous medical monitoring and complete voice and television coverage around the world. Physicist-engineers, like Soulé, Smith, and Graves, saw these demands as virtually impossible. The doctors were forced to retreat when asked what could possibly be done after diagnosis had been made on an ailing astronaut in orbit. Twenty minutes would be the absolute minimum time required to return him to Earth from orbital altitude after retrofiring. "Aeromedical clinicians finally had to agree late in 1959," said Hodge, "that they could do little if anything to help the astronaut until he was recovered." Once in orbit the pilot's safety primarily depended upon mission success. Mission success depended at this stage primarily upon positive control over reentry and recovery operations. The ground command and tracking systems were consequently more important than complete voice or telemetry coverage.[104]

Aside from the tight security surrounding the Atlas ICBM, perhaps the most closely guarded operational secret in Project Mercury was the ground control command frequencies established at strategic points around the Earth to enable flight controllers to retrieve capsule and astronaut from space in case of extreme necessity. Unlike the technological secret of the heatshield, this highly reliable command system was not classified as an industrial production secret, but rather to avoid any possible tampering or sabotage by electronic countermeasures.[105]

Once the specifications for the tracking and ground information systems for Project Mercury had been drawn up and distributed at a bidders' briefing on May 21, 1959, the Tracking Unit at Langley proceeded to select a prime contractor for the tracking network. In mid-June the organization, membership, and procedures for a technical evaluation board and source selection panel were specified. A month later the evaluation of industrial proposals was completed. The Western Electric Company, supplier of the parts and builder of the network for the American Telephone and Telegraph system, won the prime contract to build the Mercury network. After NASA sent Western Electric a letter of intent

on July 30, 1959, Rod Goetchius and Paul Lein began organizing the resources of Western Electric for Project Mercury.[106]

Soulé arranged for six site survey teams chosen from his group at Langley to travel over Africa, Australia, various Pacific islands, and North America to choose locations for communications command posts. Much of the traveling Soulé did himself; he enjoyed both the technical intricacy and the scientific diplomacy of getting foreign scientists to urge their governments to cooperate for the tracking stations.[107]

Meanwhile NASA Headquarters acquired from the National Academy of Sciences Arnold W. Frutkin, who had had experience during the IGY in dealing with the State Department and foreign governments for international cooperation in scientific affairs. Beginning in September 1959, Frutkin laid the staff-work basis with the United Kingdom for Mercury tracking stations in Nigeria and Zanzibar. Zanzibar and Mexico in particular appeared reluctant to accept at face value the United States' good—that is, civilian—intentions for Mercury. The President's brother, Milton Eisenhower, personally obtained consent for full Mexican cooperation.[108]

By the end of November, preliminary designs for the Mercury tracking network were almost completed and a five-company industrial team was developing facilities. Western Electric had subcontracted to the Bendix Corporation for the search radars, telemetry equipment, and the unique display consoles for each site. Burns and Roe, Inc., took over the engineering and construction of the buildings, roads, towers, and other structural facilities at 14 sites. International Business Machines Corporation installed the computers at Goddard Space Flight Center, the Cape, and Bermuda, and supplied programming and operational services. Bell Telephone Laboratories, Inc., designed and developed the operations room of the Mercury Control Center at the Cape, and furnished a special procedures trainer for flight controllers as well as overall network systems analysis.

Eighteen gound stations were chosen for terminals in the communications network. Eleven of these sites, equipped with long-range precision radar equipment, would double for the tracking system. Sixteen of the stations were to have telemetry receivers, but only 8 of the 18 would be located on military missile ranges where existing radar and other facilities could be used. One new station (at Corpus Christi, Texas) would have to be established in the United States. Two stations were mobile, located on tracking ships at sea; seven were built in foreign countries. In November 1959, the total cost for the system was estimated at $41,000,000. The target dates for operational readiness were set as June 1, 1960, for suborbital Atlantic missions and as New Year's Day 1961 for worldwide operations.

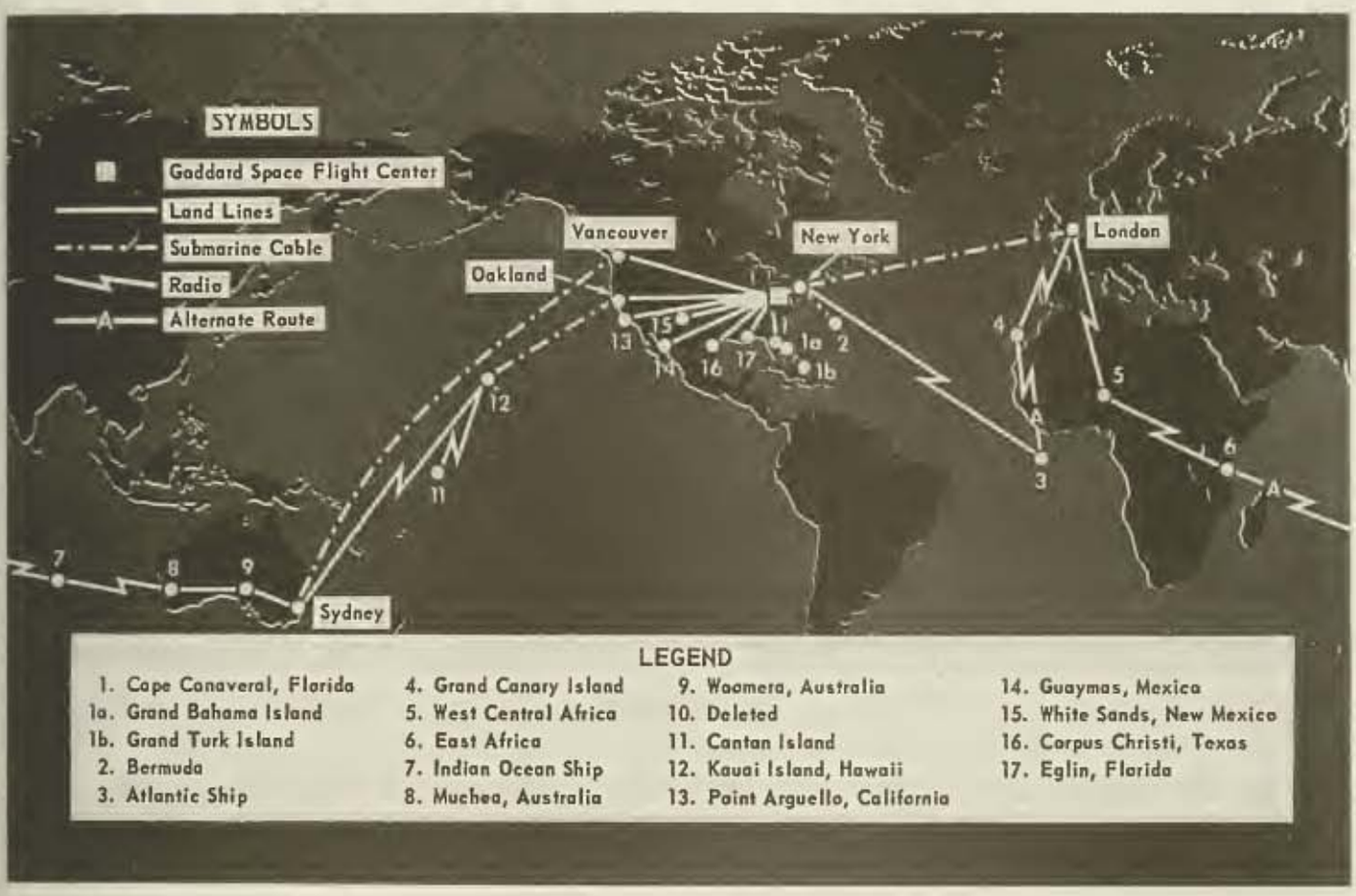
The tracking and communications network for Project Mercury was a monumental enterprise that spanned three oceans and three continents by means of approximately 177,000 miles of hard-line communications circuitry. Although

most of these wires were leased, the subtotals were likewise impressive: 102,000 miles of teletype, 60,000 miles of telephone, and over 15,000 miles of high-speed data circuits—plus the microwave radio telemetry and telecommunications circuits, which are not so easily described in linear distances. Although colossal in conception and execution, the Mercury tracking and communications network fell far short of 100-percent voice contact, telemetry contact, or tracking capability, not to speak of complete television coverage, which some aeromedical designers would have included.[109]

Despite NASA's boast about "real-time," or instantaneous, communications, the historical novelty of the Mercury communications network lay less in the temporal than in the spatial dimension. So-called "instantaneous" communications were born in the 19th century with the installation of "speed-of-light" wired communications—the telegraph, submarine cables, and the telephone. Neither radio nor radiotelephone of the 20th century brought strategic placement of telecommunications installations into such a unified network that the time of signals from antipodal sides of the world could be reduced to an "instant." Transoceanic telephone conversations between Hong Kong and Houston, for example, still delayed responses by enough time to give one the feeling of talking to oneself. Synchronous communications satellites supposedly would soon change all this, but surface communications used for Mercury operations cost some slight, but nonetheless real, time in transmission. The real innovation of the Mercury network lay in its combination of extremely rapid communications lines, linked and cross-linked around the world, culminating in digital data processing, which displayed its results in Florida virtually as soon as computed in Maryland.[110]

Only the development of digital electronic computers in recent decades made possible quick enough data digestion and display to allow communications engineers to speak of "real-time" presentations for Project Mercury. Telemetry grew more sophisticated separately in industrial and military circles until biomedical telemetry became by 1959 a recognized part of the margin of safety for manned space flight. But computer technology did not suffer this kind of bifurcated development. In fact, commercially sold digital computers were ready and actually operating under canvas tents while workmen were laying block and brick for the permanent building to surround them. No construction time could be lost if the communications and computing center was to be completed at the Goddard Center early in 1960.[111]

Harry J. Goett, formerly chief of Ames' Full Scale and Flight Research Division, took the reins as director of Goddard in September 1959. He found that the nucleus of some 150 Vanguard people had grown to approximately 500 employees. After *Vanguard III* finally terminated that program successfully on September 18, about one third of Goddard's complement turned to developing the facilities and teamwork for a space operations data control and reduction center. Actual direction of all Mercury computer programming was done from




*The worldwide Project Mercury tracking network was designed to provide the full range of communications objectives—tracking, data collection, command and control, and voice communication among ground points and with the capsule. If the Mercury Control Center at Cape Canaveral was the intellect of the Mercury flights, the Computing and Communications Center at Goddard Space Flight Center, Greenbelt, Md., was surely the nerve center. It acted as the communications link between the remote stations and Mercury Control Center. Its two IBM 7090 computers, operating in parallel, performed the continuous computation involved in determining powered-flight trajectory parameters, the smoothed present position of the spacecraft, continuous prediction of future spacecraft position, and constant data acquisition from all stations. Finally the computers calculated and transmitted to Mercury Control the quantities needed for instantaneous board display of the mission situation.*

Langley by J. J. Donegan and H. W. Tindall, Jr., of the Tracking and Ground Instrumentation Unit. But in August 1959, John T. Mengel of Goddard conferred with Soulé; together with Edmond Buckley of NASA Headquarters they decided to assign about 14 senior engineers to specific Mercury problems. From October 1959 over the next 18 months this Goddard staff tripled in size and then doubled again when the Tracking Unit's responsibility and key men were transferred to Goddard.[112]

To raise the reliability of the computers and telemetry used in Project Mercury, redundancy and cybernetics were again incorporated in design. For example,

"real-time multi-programming" was the name for a technique and some hardware developed as digestive aids for Mercury data processing machines. M. J. Buist and G. M. Weinberg of Goddard tried to describe their efforts to achieve "real-time" data:

> The problem . . . is to develop a real-time computer system capable of receiving input arriving at asynchronous times and at different rates of transmission with minimum delay. It must be capable of performing mathematical computations while input is being received and edited. Simultaneously, it must send out information to numerous sites in varied formats and at varied speeds without human intervention.[113]

For this purpose two IBM 7090 transistorized computers were installed at Goddard, in Maryland. Two older model IBM 709 vacuum tube computers, one installed for NASA on Bermuda and the other an Air Force "IP" (impact predictor) for the Range Safety Officer at the Cape, were modified to handle a computer logic designed with equivalent alternative programs rather than with the usual subroutines. By means of special memory traps and automatic switching, the most critical data reduction operations were redundantly programmed into the IBM machines to ensure cross-checks on the man-rated machines in orbit.

Curiously, the difference between the IBM 709s and 7090s, so far as reliability was concerned in 1959, was the same difference the Mercury team encountered with miniaturization techniques. Although solid-state electronic devices like transistors, printed circuits, and molectronic capacitors promised tremendous savings in space, weight, and trouble-free operation, they were as yet so new that their reliability was not proved. The two 7090s at Goddard, therefore, were necessary redundancies for the heart or brain of the global tracking and target acquisition grid. The two independent and separate 709s at the Cape and Bermuda, amply stocked with spare parts, had the more limited but no less critical job of computing whether orbital launch conditions had been met. The two new transistorized computers at Goddard should man-rate the worldwide Mercury switchboard and data reduction. The older, more reliable vacuum-tube computers in the Mercury launch area should ensure nearly perfect orbital insertion conditions before the point of no return.[114]

That point of no return was first selected as insurance against landing in Africa. Later refinements to the "go/no go" decision point incorporated parameters from the standardized atmosphere, better drag coefficients, perturbation theory, preferred recovery areas, the improved Atlas booster, and the heavier Mercury capsule. These and many other intertwined considerations made the efforts of man-rating the machines for Mercury seem almost as limitless a task as space is a limitless continuum. They had the effect of canceling, for the time being, STG's hopes for an 18-orbit, or daylong, final Mercury mission.

By the end of 1959 Project Mercury was well under way on many different fronts. The American astronauts, supposedly shifting from academically oriented training to practical engineering and operational exercises, were widely known as

men in training to challenge the impressive Soviet performances in space. Most recently, *Lunik III* had photographed the unknown side of the Moon for the first time. A few Soviet names and faces appeared in Western publications as challenging indications that the U.S.S.R. too was training pilots for space flights. But the imagination and hopes of the American people were pinned on the seven of their own, each of whom had the chance of being the first human being to orbit Earth. Publicized in accord with the law and in response to public demand, the plans and progress of Project Mercury were for the most part open knowledge. NASA Headquarters was swamped with inquiries of all kinds from all sorts of people. The field managers of Mercury had ruefully discovered that people, or at least reporters, were more interested in people than machines, so they allowed "Shorty" Powers to skew publicity toward machine-rating the men rather than man-rating the machines.[115]

# VIII

## Machine-Rating the Men

(JANUARY–JUNE 1960)

JUST as the safety of the pilot flying the Mercury mission depended primarily on the reliability of the boosters, so the overall success of the mission would depend primarily on the adaptability of the man inside the capsule. This proposition, recognizing man and machine as directly interdependent, had been far from evident at the beginning of the project. But by the middle of 1960 the developers of Mercury had encountered enough troubles with various automatic systems to dissipate much of their faith in automata. They began to believe that it might be simpler to train toward human perfection and safer to teach the operations team to act automatically than to try to make electromechanical systems operate faultlessly. If the gaps left after technologically man-rating the machines could be filled with techniques learned by machine-rating the men, then lack of experience need not jeopardize either the man or the mission.

Early in 1960 two peerless feats in hydronautics complemented mankind's first infantile steps toward astronautics. Two uncommon vessels named *Trieste* and *Triton*, sponsored by the United States Navy, made voyages probing the plenum of the seas only a year before men became able to venture upward into the near vacuum. While "space" was being defined popularly as the region above the atmosphere and below the ionosphere, man also conquered the aqueous seven-tenths of Earth's surface space between the atmosphere and the lithosphere for the first time in history. Demonstrating remarkable closed ecological systems and significant integrations of men and machines, the *Trieste* descended to the bottom of the deepest known point in the oceans and the *Triton* "orbited" the Earth underwater.[1]

The *Trieste* and *Triton* voyages symbolized an accelerating translation of science fiction into fact at the beginning of the sixth decade of the 20th century. These voyages not only dramatically demonstrated man's ability to explore and pioneer new frontiers but they also symbolized some complex interrelationships in the sociology of science, invention, innovation, and discovery. Project Mercury likewise promised to exhibit the social energy of a civilization intimately interlocked with industrial technology, governmental organization of manpower, and an

accumulation of usable knowledge. Motivationally, too, Mercury grew out of the curiosity, courage, and creativity of individual men who wanted to do "unnatural" deeds. An age-old question of humanistic inquiry—what is human nature?—seemed to become rhetorical, and, as preparations for manned space flight neared completion, inverted: what is *not* natural to man?

No one doubted at the beginning of 1960 that someone was going upward into space shortly, but precisely who, when, where, and even why were highly controversial questions. NASA Administrator T. Keith Glennan predicted the first Mercury suborbital flight within the year. Soviet spokesmen previewed their mid-January rocket tests over the Pacific as a preparation for placing man in space. Winds from conflicting opinions expressed by political, military, scientific, and industrial critics of American policy regarding space technology began to brew some squalls when NASA asked that almost $108 million of its total budget request of $802 million be appropriated for manned space flight development in fiscal 1961. Whether Mercury would finally cost $250 or $350 million, as was now variously estimated, it would still be a small fraction of the cost of the great Saturn rocket, not to mention other NASA projects.[2]

While the Eisenhower administration rejected the "space race" image attached to Mercury, Congress pressed for a greater sense of urgency, NASA Headquarters sought supplemental funds, and the Space Task Group concentrated on reconciling schedules with quality control. There was a detente in the cold war until the controversial U–2 incident in May 1960. But even during this thaw STG, as the technical coaching staff for the prime American contestant, became steadily more enmeshed in the confused competition between the United States and the Soviet Union to be first with its man in space. While Maxime A. Faget was being honored as one of the top 10 young men in government service for his designs of the Mercury capsule, couch, and escape concepts, Abe Silverstein stated publicly, "We feel no urgency to move the program unsafely." But the political pressure to produce would increase rapidly as 1960 wore on.[3]

At the end of January, Little Joe 1–B finally, with a boilerplate capsule, proved the basic aerodynamic viability of the Mercury abort concept. McDonnell Aircraft Corporation's first production hardware, which happened to be capsule No. 4, was delivered on demand only half-finished to Langley, where it was fitted with instruments like Big Joe's for the first flight to mate the Atlas booster with the "real McDonnell" head. As it turned out, the only other flight test for Mercury during this half year occurred at Wallops Island on May 9. There and then, McDonnell's Mercury capsule No. 1, so named because it had been first on the assembly line, was yanked by its escape rocket from the beach abort position to begin successfully the qualifying flights for the McDonnell capsule. It took only 14 months to build and deliver this first capsule with its most critical systems ready to be qualified for basic technical performance. Meanwhile qualification tests in laboratories began in earnest. No mechanisms were more difficult to qualify than those most intimately related to the human system.

## Controlling the Hostile Environment

To replace the old warhead payloads with inhabitable cockpits on the missiles used to transport man into space required reliable, lightweight means of sustaining life beyond the atmosphere. When man ascends from the bottom of the ocean of air where life as we know it has evolved, he must stay inside a pressurized cell of air or die in the vacuum of space. Engineering the environmental cocoon to provide the basic metabolic needs of man became, through 1959 and 1960, one of the most complex and critical aspects in Mercury's development. Aristotle's classical anthropocentric elements—earth, water, air, and fire—correspond roughly to man's need for the gravisphere and atmospheric pressure, for hydration and waste disposal, for oxygen to breathe through lungs and skin, and for temperature and humidity control. Safety required that these life systems be redundant wherever feasible. The oxygen envelope, for instance, should be contained within the welded walls of the pressure vessel, but in case of leak, puncture, or blowout, the astronaut would wear a suit that was a second inner casing, fully capable of life support in a decompressed capsule.[4]

The environmental control system for Mercury, logically divided into the cabin and suit subsystems, grew directly out of previous aviation experience in maintaining men and machines at high altitudes. McDonnell had to seal hermetically the pressure vessel within prescribed limits; a subcontractor developed the dual air-conditioning system. Because the clothing needed for space travel turned out to be unavailable from the shelves of government issue, another subcontractor was called upon to make a full-pressure suit that would in effect be a secondary cabin.

When McDonnell and STG engineers first considered the problems of the pressurized cabin, they sought the experience of the foremost company of industrial specialists on the subject. AiResearch had grown since the 1930s into the Manufacturing Division of the Garrett Corporation, the Nation's primary supplier of the needs of the pressurized flight industry.[5] In January 1959 the three groups began to discuss the most realistic design criteria for ambient and partial gas pressures, air and water regeneration methods, thermostats, and heat exchangers. R. A. Fischer, Edward H. Olling, and Richard C. Nelson of Garrett, Herbert R. Greider, John R. Barton, and Earl A. Reed of McDonnell, and Stanley C. White and Richard S. Johnston of STG were the principal designers of this system.

While the process of fabricating the pressure-vessel shell by the fusion-welding techniques of William Dubusker and his production engineers was cut and tried on the factory floor, the important question of cabin atmosphere gas composition was being debated by physicians and physicists. Should the cabin air and pressure imitate "sea level" air mixtures of nitrogen and oxygen, or should the space cabin endorse the experience of aviation and use at highest altitude whatever would guarantee oxygenation?[6] Stanley White championed the latter position forcefully, in response to rather late outside criticism that "shirtsleeve" environ-

mental air might be preferable. John F. Yardley and Barton, Faget and Johnston agreed emphatically that a five-pound-per-square-inch pressure of pure oxygen would be far more practical for saving weight, controlling leakage, and avoiding the extremely difficult problem of providing reliable oxygen partial-pressure sensors. Faget explained STG's choice:

> The most important consideration in choice of a single gas atmosphere is reliability of operation. If a mixed gas atmosphere were used, a major increase in complexity in the atmospheric control system and in monitoring and display instrumentation would have resulted. Furthermore, the use of a mixed gas system would have precluded the use of simple mechanical systems for a great number of these functions which in itself would have decreased the reliability of performance.[7]

Reduced to practice, these designs had evolved into hardware for three spherical oxygen bottles, tested at 7500 pounds per square inch, with simple regulator valves, a lithium hydroxide canister to remove carbon dioxide and odors, an evaporator heat exchanger (its water would boil around 35 degrees F at a 100-mile altitude), and a simple pulsating-sponge water removal system, all to be located beneath the astronaut's legs. Blowers, a fan, snorkels, and plumbing were also included to make the capsule livable under the extremely diverse conditions existing before, during, and after an orbital mission. The most novel parts of this system were the high-pressure oxygen bottles, the use of lithium hydroxide, and the "sponge squeezer" to collect perspiration and respiration water vapor from the cabin atmosphere. Cleanliness in the manufacture of these components was so important that AiResearch built the first "surgery," or "white room," for Mercury fabrication in the summer of 1959.[8]

McDonnell and AiResearch engineers consulted the voluminous literature on aeromedicine before imposing STG's specific requirements on top of the state of their art. One of the best independent guides to that state was a report prepared in mid-1959 by A. B. Thompson of Chance Vought Astronautics, entitled "Physiological and Psychological Considerations for Manned Space Flight." Thompson compiled a consensus on environmental parameters derived from a wide number of sources; then he presented these factors systematically in the order of their occurrence on a typical orbital mission. Concerning the internal atmospheric environment, he drew heavily from submarine, as well as aviation, practice and expressed particular concern over abnormal toxicities peculiar to space conditions. Regarding temperature tolerance, Thompson wrote:

> Man can exist and carry out simple tasks in environmental temperatures from −40° to 140° if suitable clothing is worn for the low, and if humidity is kept at 30–50% for the high. Time of exposure to high temperatures should be well below man's tolerance limits. Up to 160°F can be withstood for 20 minutes. Such temperature highs are possible at reentry into atmosphere. Insulation, double walls, cabin temperature and atmosphere cooling should limit the heat of cabin to less than 140°F even when skin temperature of the vehicle is much higher.[9]

Between John Barton of McDonnell and Edward Olling of AiResearch, the system specifications for environmental control began to emerge in mid-1959, subject to continuous reappraisal as other systems also took shape. Their original set of design parameters rather arbitrarily selected 400 British thermal units per hour for one man's average heat production rate over 28 hours, and an ambient pressure of 5 pounds per square inch circulating through the cabin, with a breathable supply of oxygen at the partial pressure of 3.8 pounds. An assumed oxygen consumption rate of 500 cubic centimeters per minute allowed a slight margin for suit leakage. Setting the average rate of perspiratory and respiratory water production at 6 pounds per day dictated the weight and size of their system's hardware.

Particularly knotty for the development of the active air-conditioning system and the passive insulation to control the cabin temperature was a problem that Barton described in terms of applied thermodynamics:

> Studies of launch, orbit and reentry heating effects disclosed that the insulation requirements for the cabin side-walls for the orbit and reentry phases were diametrically opposed. In orbit it is desirable to lose heat from the side-walls and during reentry it is necessary to prevent the entry of heat. The reentry phase, being more critical, dictated the side-wall insulation. In orbit, the insulation becomes an almost perfect heat barrier and dictates that the cabin cooling be primarily accomplished by the cabin heat exchanger.[10]

At the end of July 1959, Barton and Frank G. Morgan, Jr., met with 18 STG engineers, including all the astronauts, to describe the basic designs and developmental problems, especially leaky instrumentation fittings, for the system now known as "the ECS." Faget, White, William K. Douglas, William S. Augerson, and Robert B. Voas, and the ECS systems engineers, Richard Johnston, Frank H. Samonski, and Morton Schler, all warned that the design parameters were set too low. They demanded larger margins of at least 1000 British thermal units per hour for astronaut heat generation, at least 7 pounds per day assumed water production, and certainly no less oxygen pressure in the suit than in the cabin.[11] Greider and Barton warned the astronauts to learn early and thoroughly the symptoms of hypoxia in themselves so they could take action soon enough to ensure an emergency oxygen supply. Otherwise probe sensors of some sort in the nostrils or the lungs might be necessary.

McDonnell hurried the building of a "man-rating" environmental system test chamber through September 1959, so that a reliability test program for each subsystem could be conducted, complete systems tests could be scheduled, and astronaut familiarization training could begin as soon as possible. By the end of the month, Gilbert B. North, as McDonnell's test astronaut, had endured so many failures or inadequacies in the bench testing that STG sought the aid of physiologists from Duke University School of Medicine and from the Navy Air Crew Equipment Laboratory in Philadelphia to help speed the man-rating of the environmental control system. At the end of January 1960, neither the cabin nor the suit environmental control system had passed its test to operate as designed for 28 hours.

Richard Johnston reported that experience with the system was still "rather meager." He urged aeromedical investigators to provide more "realistic metabolic data" for his engineers to use in system redesign.[12]

Difficulties with the body ventilation and post-landing snorkel ventilation subsystems continued troublesome through 1960. Extensive testing at AiResearch and intensive manned tests at McDonnell beginning in June slowly eradicated most of the "bugs" plaguing the reliability of the environmental control system. A robot "crewman simulator," designed primarily by Charles F. Jahn and Eugene Wulfkehler at McDonnell, served to calibrate the physical parameters for average human inputs and outputs to this closed ecological system. Then, too, Gilbert North and Herbert Greider learned to outwit the peculiarities of the mechanisms to avoid hypoxia, dysbarism, and hyperventilation. The initial manned tests of the ECS hardware were endured by McDonnell volunteers; occasionally the Mercury astronauts would observe. Gas analysis problems delayed the accumulation of reliability records and the verification of certain operational procedures, such as ground purge and ground cooling, until early 1961.[13]

## Suiting Up for Space

The pressure suit for Project Mercury was designed and first developed during 1959 as a compromise between the requirements for flexibility and adaptability. Learning to live and move within aluminum-coated nylon and rubber garments, pressurized at five pounds per square inch, was like trying to adapt to life within a pneumatic tire. Led by Walter M. Schirra, Jr., whose speciality assignment this was, the astronauts literally wrestled with the most elementary problem in becoming machine-rated—wearing the suit.

Back in February 1959, Maxime Faget and Stanley White became convinced that the so-called "pressure" suits being used by Air Force and Navy test pilots were rather "high-pressure" and partially anti-g flying suits. Ever since 1947 the Air Force and the Navy, by mutal agreement, had specialized in developing partial-pressure and full-pressure flying suits, respectively, but a decade later neither type was quite satisfactory for the newest definition of extreme altitude protection. Such suits would require extensive modifications, particularly in their air circulation systems, to meet the needs of the Mercury space pilots. The first suit conference on January 29, 1959, attended by more than 40 experts in the art of tailoring for men engaged in high-altitude flying, had recommended an extensive evaluation program.[14] Through the spring three primary competitors—the David Clark Company of Worcester, Massachusetts (a prime supplier for Air Force pressure suits), the International Latex Corporation of Dover, Delaware (a bidder on a number of government contracts involving rubberized material), and the B. F. Goodrich Company of Akron, Ohio (suppliers of most of the pressure suits used by the Navy)—competed to provide by the first of June their best products for a series of evaluation tests.





*Few systems in the Mercury program were modified as frequently or as drastically as the space suit. Shown here are an early model worn by Slayton in 1960 (above) and the end-of-Mercury model worn by Cooper at the time of his flight in May 1963 (right). Cooper is followed by suit technician Al Rochford.*

NASA had requested the Air Force Aeromedical Laboratory at Wright Air Development Center and the Navy Air Crew Equipment Laboratory in Philadelphia to plan and perform evaluations of the different test suits before mid-July. The Clark and Goodrich suits ranked highest in both evaluation programs, but predictably the Air Force favored the Clark suit and the Navy the Goodrich suit. After an evaluation conference on July 15 at Langley, the chairman, Richard Johnston, informed all parties of STG's decision to work with both the Clark and the Goodrich companies for several more months to allow further concurrent development and evaluation of various combinations of suits and ventilation systems.[15] By the end of August, William Augerson and Lee N. McMillion of STG recommended that "the suit should not be expected to cope with all the deficiencies of the Mercury capsule." The close interface between pressure suit and environmental control system caused enough problems to delay the formulation of suit specifications until October, but Goodrich was awarded the prime contract for the Mercury space suit on July 22, 1959.[16]

One of the most senior employees of the Goodrich Company was Russell M. Colley. In 1933, Wiley Post returned from the first solo flight around the world and wanted some kind of rubber suit that would enable him to fly his famous aircraft *Winnie Mae* above the record 47,000-foot altitude. Colley had designed an aluminum helmet resembling those used by marine divers and had stitched together on his wife's sewing machine the first crude space suit. The next year Colley and his company had designed and developed a more flexible flying suit for Wiley Post, with an off-center face plate to accommodate Post's one-eyed vision. In 1952, Colley had designed and helped develop swivel joints of air-tight bearings and fluted fittings for pressure suits fabricated by Goodrich for the Naval Bureau of Aeronautics. In 1959, Colley, along with Carl F. Effler, D. Ewing, and other Goodrich employees, was instrumental in modifying the famous Navy Mark IV pressure suit for NASA's needs in orbital flight.

Although the decision to let the capsule itself provide primary protection minimized the difference between corseted, pressurized g suits and a "space suit" for Project Mercury, the redundant suit environmental control system required complicated modifications and continual refittings.

The Task Group had discovered during 1959 that each Mercury capsule would have to be specially tailored to its own mission objectives. Pressure suits also were designed individually according to use—some for training, others for evaluation and development. Thirteen operational research suits first were ordered to fit astronauts Schirra and Glenn, their flight surgeon Douglas, the twins Gilbert and Warren J. North, at McDonnell and NASA Headquarters, respectively, and other astronauts and engineers to be specified later. A second order of eight suits supposedly would represent the final configuration and provide adequate protection for all flight conditions in the Mercury program.

The three major parts of the space suit—the torso coveralls, the helmet, and the gloves—were fabricated by techniques and procedures similar to those already

in use in the manufacture of full-pressure flying suits. But the air system operation was unusual:

> The Mercury headpiece is a single cavity design with suit ventilation air exiting through the exhaust valve located in the right cheek area. This system is known as the "closed" or "single gas" system and utilized one air source for ventilation as well as breathing. This concept, which is desirable in space missions, permits simplicity of design and minimum weight of the ventilation and respiration equipment.[17]

According to Lee McMillion of STG's Life Systems Branch, the Big Joe reentry heating test in September 1959 allowed the developers of the pressure suit to remove much of the insulation previously thought necessary. This improved somewhat the mobility of the astronaut under full pressurization. By the end of the year McMillion, Colley, Schirra, and Glenn A. Shewmake, STG's "tailor," chose to modify the suit to facilitate mobility in the capsule rather than repattern for a more generally mobile suit. Schirra had felt many pressure points and was severely constricted in recent tests. His discomfort was traced to the design conservatism that had accepted the g suit and oxygen mask concepts used for the Navy Mark IV and Air Force X–15 flying suits. Furthermore, each time these prototype space suits were pressurized and worn, they stretched out of shape.[18]

Throughout the spring of 1960, fittings and tests with new textiles, different materials, and other human models continued until they finally solved the stretching problem. In mid-March a committee of eight members from STG, McDonnell, the Navy, and Goodrich decided on the final design features for the Mercury space suits. All kinds of minor troubles with zippers, the visor, the segmented shoulder, lacings, straps, snaps, seams, valves, underwear, gloves, microphones, and neck dams continued. But after a "gripe session" in mid-May 1960, the astronauts and their tailors essentially agreed on what the well-dressed man should wear into space.[19]

During an orbital flight, certain physiological limitations were expected to establish the requirements for matching man and machine in one smoothly functioning system.[20] In the area of noise and vibration, for example, research during the 1950s had led to the conclusion that 140 decibels, in the broad spectrum between 100 and 12,000 cycles per second, was the most that man could stand for durations of four or five seconds. Acceleration tolerances were rising, thanks to knowledge gained by centrifuge and rocket sled tests, but above 6 g pilots could breathe only by forcing abdominal constriction and could move effectively only their hands and fingers. An oxygen pressure inside the lungs corresponding to that of 100 millimeters of fluid mercury was judged necessary to preclude any symptom of hypoxia. To guard against the danger of "bends" (caisson disease or dysbarism), the cabin pressure should not be more than twice the suit emergency pressure of 180 millimeters of mercury. No more than two percent of carbon dioxide by volume at sea level should be permitted.[21] Other limitations, including extremes of temperature, humidity, radiation, and accumulating toxic

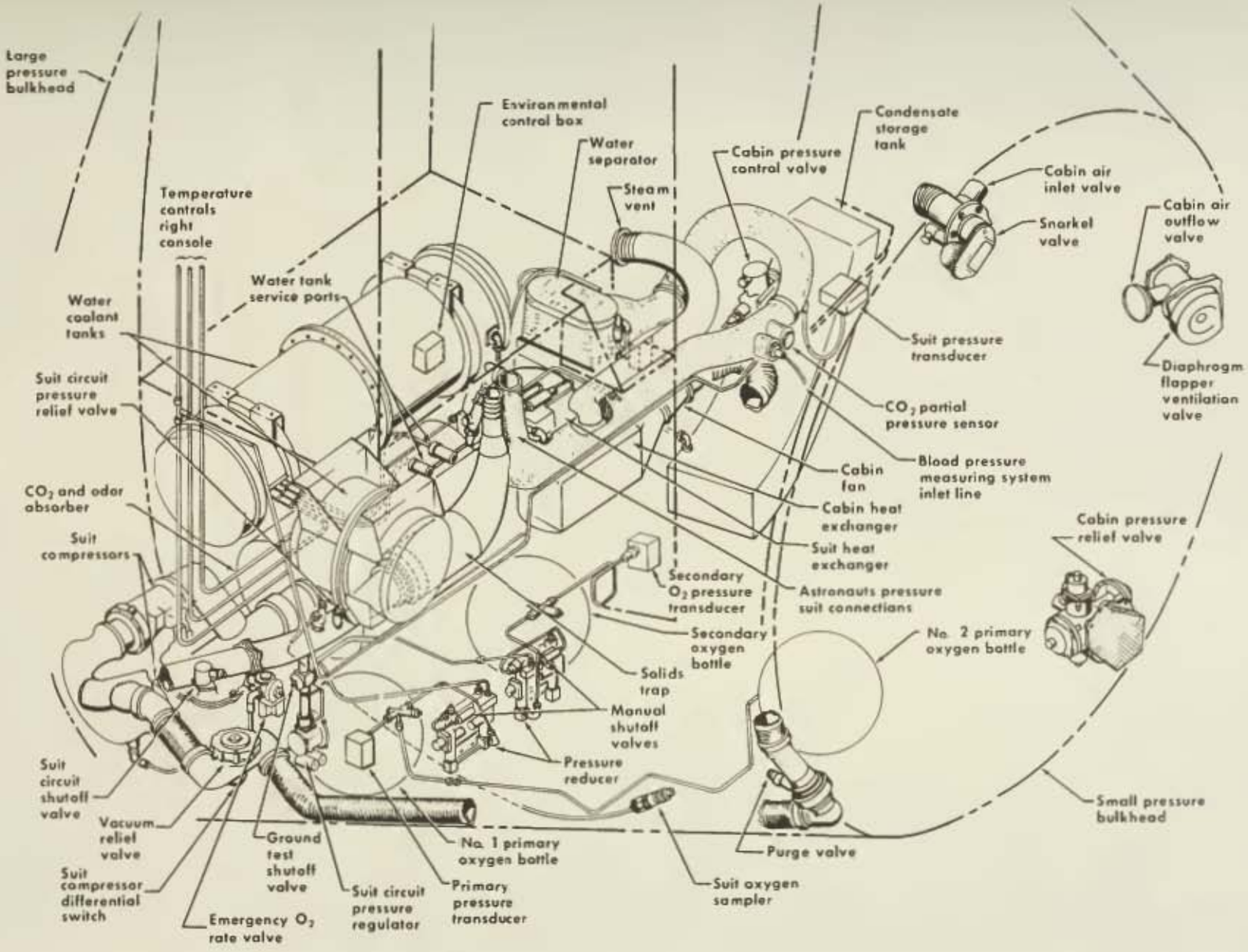
gases from carbon monoxide, ozone, metal, and plastic fumes, also became "human parameters." Warning instruments in the capsule relied primarily on stimulating the astronaut's senses of sight and sound; psychologists also studied the feasibility of using his senses of touch and smell to aid him in diagnosing malfunctions.[22]

During the fifties academic and medical studies in sensory deprivation made an important, if indirect, contribution to the building of the spacecraft and the training of the astronauts. Made notorious by the experience of American prisoners of war who had been isolated and "brainwashed" in North Korean prison cells, the effects of isolation were attacked on many fronts. At McGill University, in Canada, at the University of Rochester in New York, and at the National Institute of Mental Health in Bethesda, Maryland, famous sensory deprivation experiments reduced all physical stimuli to near zero. Suspending people in water of body temperature in blacked-out, soundproof rooms at Bethesda revealed that normal men, regardless of their motivations, could hardly stay both conscious and sane if deprived of all sensory stimuli beyond three hours. Physicians and psychiatrists were warning in 1956 and 1957 that

> if one is alone enough and at levels of human and physical stimulation low enough, the human mind turns inward and projects outward its own contents and processes. . . . Man's mental state is dependent on adequate perceptual contact with the outside world. . . . Isolation produces an intense desire for extrinsic sensory stimuli and bodily motion, increased suggestibility, impairment of organized thinking, oppression and depression, and in extreme cases, hallucinations, delusions, and confusion.[23]

Such background studies strengthened aeromedical demands, originating outside NASA and STG, for continuous communications between the ground and an orbiting man, for increasing the number of meaningful cues to be given the man in space, and for accenting significant tasks to be performed by the man inside the capsule. There was room for controversy here, but STG and NASA believed the hypothetical risks did not justify the very large outlay of money, men, and time that a continuous communication network would have required.

If outside advice of this type was not always taken, there was still a conscious effort to solicit it. One of the most useful means of dialogue was the presenting of papers at meetings of professional societies. The size, lead time, and innovating nature of Project Mercury, together with the impetus from NASA's open information policy, all reinforced the normal professional obligation to inform and meet the judgment of one's colleagues. Thus it was that, on January 25, 1960, several leading engineers from the Space Task Group were in New York for the annual meeting of the Institute of Aeronautical Sciences and presented papers reviewing the scope and recent results of their research and development program.[24] In one of these, Charles W. Mathews set forth the operational plans for the orbital mission. He did not mention the role of the pilot until the end




*Environmental Control System.*

of his remarks. He then offered a summary list of eight activities to illustrate what the astronaut must be prepared to do: the Mercury pilot should communicate with ground stations, make scientific observations, monitor onboard equipment, control capsule attitude, navigate and fire retrorockets, initiate emergency procedures, activate escape system if necessary, and deploy landing parachute if required. Any one of these activities could conceivably save the mission.[25]

The degree of control over his own destiny that the astronaut might have during the first orbital flights steadily increased throughout 1959 by virtue of the development of two new semi-automatic control systems: fly-by-wire, interposed in the automatic stabilization and control system (ASCS), and the rate command system (rate stabilization control system, or RSCS), superimposed on the manual proportional control system. Further elaboration and sophistication of the hardware took account of man's flexibility by providing for the use of more than one system at a time. In addition to the "last resort," or manual-proportional, method of attitude control, other uses of the astronaut as a source of mechanical power were being incorporated to the mutual advantage of reliability and flexibility. Turnkey handles and pull rings were added to duplicate virtually every automatic function of the mission sequence.

In April 1960, Edward R. Jones, the chief psychologist at McDonnell, feeling that a vigorous offense is the best defense, argued in public that man in the Mercury capsule not only could act as an observer as well as the observed but should be considered an integral part of the system to increase the probability of mission success. Having just completed extensive studies of man's vision from the new centerline window, Jones supervised studies of other expected sensations during the Mercury orbital flight.[26] As the hardware and manned capsule systems tests progressed, Jones had more reason for his optimism about man's ability to perform effectively in space, once his life-support requirements were met. Concerning higher mental processes, Jones, speaking in a symposium at the Iowa Academy of Science, where James A. Van Allen represented the instrumentalists and John Paul Stapp represented the experimental physicians, maintained his positive approach:

> Most of the astronaut's tasks will involve complex mental activity even though some may be on a near reflex level as a result of constant practice. It is not expected that impairment of these functions will occur under normal vehicle operation. Stress and an abnormal atmospheric composition, if present, could cause some impairment of the higher mental functions.
>
> It should be apparent that the training of the astronaut in the operation of the space vehicle will be critical. Much of the physiological training and conditioning will be given on a part task basis in human centrifuges, and pressure and heat chambers. The operation of the vehicle can be practiced over and over again in a capsule simulator . . . built for Mercury. Overlearning far beyond the point that apparent progress stops seems to be the best guarantee that the astronaut will have developed response patterns that are least apt to deteriorate under the stresses of orbital flight.[27]

## Seven Astronauts-in-Training

When the astronauts first had reported to the Task Group at the end of April 1959, they had been oriented with a series of lectures covering every aspect of STG's progress. After a welcoming general briefing by Paul E. Purser, Alan B. Kehlet delivered their first lecture on April 29, explaining the configuration and the escape system. Following two weeks of such lectures, the group began to visit contractor facilities for familiarization with mockups, hardware, and manufacturing processes. They went to the launch site at Cape Canaveral. At various military and medical centers, each man learned to know himself still better through training sessions in the pressure suit, in heat chambers, in heavy concentrations of carbon dioxide, and in parabolic flying. By July, Robert Voas, the astronauts' training officer, had prepared tentative curricula and schedules; during unscheduled times, each man was expected each week to fly for three hours, to spend six hours on his specialty area, and to exercise at least four hours in athletics. The primitive jury-rigged air-bearing platform trainer also was ridden by each astronaut for two hours per week at first.

During August 1959, each man spent approximately two weeks at Johnsville riding the centrifuge in "closeloop" (i.e., with man in the control circuit) simulation of the exit and reentry profiles. In September each man spent a week at McDonnell, another at the Cape for the Big Joe shot, and another at the Goodrich plant in Akron being fitted for his pressure suit. And in October 1959, the seven pilots, by now reluctant celebrities, traveled to Edwards and Vandenberg Air Force Bases, to the AiResearch and Convair factories, and to the Naval School of Aviation Medicine at Pensacola for different kinds of centrifuge runs and for training in survival, disorientation, and communications.[28]

Although everyone who read the news or looked at *Life* magazine knew that the Mercury astronauts had been assigned specialty areas befitting their profession as engineering test pilots, few could see the logic of those assignments.[29] M. Scott Carpenter accepted responsibility for communications and navigation because as a Navy lieutenant he had had special training in airborne electronics and celestial pathfinding. Virgil I. Grissom, who had earned a degree in mechanical engineering from Purdue University in 1950, became the expert for the group on the complicated electromechanical, automatic, and manual attitude-control systems. The senior man in age and date of rank, John H. Glenn, Jr., had the most experience in flying varieties of aircraft and could therefore make the best contribution to cockpit layout. Walter M. Schirra, Jr., born to a flying family and a graduate of the Naval Academy, took a special interest in life-support systems and the pressure suits. Alan B. Shepard, Jr., like Carpenter and Schirra, had the background training of the naval flier for specializing in tracking and recovery operations. L. Gordon Cooper, Jr., and Donald K. Slayton, both Air Force captains, accepted the jobs of astronaut liaison with the developers of the Redstone and the



*Just as they did as military test pilots before they joined the Mercury program, each astronaut felt his first responsibility to be that of the engineer-test pilot responsible for knowing his spacecraft and its equipment so well that he could quickly and with certainty evaluate its performance. In these photos, Cooper (left) performs an engineering check on a spacecraft and Schirra (below) inspects a hatch in white room at the McDonnell Aircraft Corp. plant.*



Atlas boosters, respectively. Cooper, the youngest of the group, had been dedicated to flying since childhood and had worked with performance engineering similar to what he would encounter at Redstone Arsenal. And Slayton, with a degree in aeronautical engineering from the University of Minnesota and having worked for two years with the Boeing Company in Seattle, was best fitted to report on the progress of the Atlas booster at Convair/Astronautics.

The astronauts' specialty assignments had some direct effect on the redesign of the Mercury suit, cockpit layout, and capsule hatch and window systems. More importantly, the assignments kept the crew informed in depth on the problems and progress in major areas of concern to all members. Carpenter and Shepard kept tabs on the progress of the Tracking Unit at Langley and of the Goddard Space Flight Center in preparing to operate the network. While Carpenter monitored the development of onboard navigation equipment, such as the Earth-path indicator and starfinder charts, Shepard paid special attention to recovery at sea and to problems of egress from the capsule and survival on Earth in inhospitable environments. Grissom studied the electromechanical worries of Robert G. Chilton, Thomas V. Chambers, and other controls engineers. Schirra worked closely with Richard Johnston and John Barton on the environmental system, and with Lee McMillion, Gilbert North, and the Goodrich people in preliminary fittings of the pressure suit. Cooper and Slayton spent much of their time traveling to Huntsville and southern California, respectively, attending meetings and offering suggestions from the pilot's viewpoint on how best to mate a manned capsule with the Redstone and Atlas missiles. Glenn, meanwhile, paid special attention to optimizing the cockpit and improving simulation training.[30]

Within months after joining the Space Task Group, the more eager than anxious astronauts found themselves barraged by questions regarding their emotional feelings about being catapulted into orbit. In answer to one such set of questions, posed in an author's questionnaire for a high-school textbook, Schirra perfunctorily replied that it was only natural for a test pilot to want to participate in the most advanced form of manned vehicular travel. Schirra's desire to "go higher, farther, and faster" than previously had been possible was to him neither mysterious nor worthy of introspection; it was simply the professional commitment of them all and of STG to want to expand the test pilot's "envelope." [31]

Partly because of this kind of natural public interest and partly because the civilian space agency had a statutory mandate to conduct educational publicity, NASA Headquarters, after investigation and decision, encouraged the astronauts to stay together and to accept the fringe benefits of a single private-enterprise publishing offer arranged in outline even before their selection. This precluded eventual competitive bidding for individual story rights. On August 5, 1959, the astronauts sold their "personal stories" to the highest bidder, Time-Life, Inc., for $500,000, an amount to be equally divided regardless of who might be chosen first to fly in space. This money was to be paid in installments throughout the program. The astronauts' wives also subscribed to the contract. Defense De-

partment policy had been followed by the NASA decision because the astronauts were active-duty military officers.[32] There were similar precedents for test pilots, Presidents, and submarine captains. Many Congressmen approved this form of extra life insurance for the astronauts' wives.

A public furor, nevertheless, arose in the press over these exclusive rights to publish the memoirs of the seven. Few other peripheral policy decisions regarding Project Mercury were to become so controversial in the long run. As the waiting period before an astronaut flew in space stretched on, public interest grew; the competition among newsmen and media increased; the line between personal and public domains blurred. NASA and STG were forced to contend with no small amount of adverse and even spiteful publicity from indignant correspondents who were not of the favored few. Warren North, two days after this contract was signed, advised Silverstein about it and warned of other impending difficulties, including a loss of privacy to a degree the astronauts might not have anticipated.[33]

The agreement, arranged without fee by C. Leo DeOrsey, a prominent Washington lawyer and sportsman, assigned all magazine and book rights to Time-Life, Inc., for "non-official" feature stories on the astronauts and their families. Since it was cleared by NASA's legal and public relations chiefs, John Johnson and Walter T. Bonney, the astronauts and the Task Group had to adapt themselves to this policy. John A. "Shorty" Powers, at least, was relieved of one headache and was not displeased with the arrangements.[34]

Although Robert Voas at first had designed an orderly curriculum for the astronauts, their activities soon became so diverse and the group separated on sorties for their specialties so often that the academic approach became impossible. The coordination of astronaut training became his chief duty. Voas gathered and trained a team of training specialists. George C. Guthrie had responsibility for improving training aids, procedures, and simulation devices; Raymond G. Zedekar arranged the lecture series; Stanley Faber conducted the four-phase centrifuge training program on the Johnsville "wheel." By the end of 1959, each of the astronauts had trained for about 10 hours riding the gondola at Johnsville. Voas, meanwhile, turned his attention to an extensive astronaut task analysis, which paralleled the work of Edward Jones at McDonnell.[35] Just before Christmas 1959, John Glenn privately described his training experiences in a letter to a friend and fellow pilot:

> This past 8 or 9 months has really been a hectic program, to say the least, and by far the most interesting thing in which I have ever taken part, outside of combat.
>
> Following our selection in April, we were assigned to the Space Task Group portion of NASA at Langley Field, and that is where we are based when not traveling. The way it has worked out, we have spent so much time on the road that Langley has amounted to a spot to come back to get clean skivvies and shirts and that's about all. We have had additional sessions at Wright Field in which we did heat chamber, pressure chamber, and centrifuge work and spent a couple of weeks this fall doing additional centrifuge work up at

Johnsville. This was some program since we are running it in a laydown position similar to that which we will use in the capsule later on and we got up to as high as 16 g's. That's a batch in any attitude, laydown or not.

With the angles we were using, we found that even lying down at 16 g's it took just about every bit of strength and technique you could muster to retain consciousness. I found there was quite a bit more technique involved in taking this kind of g than we had thought. Our tolerances from beginning to end of runs during the period we worked up there went up considerably as we each developed our own technique for taking this high g. A few runs a day like that can really get to you. Some other stuff we did up there involved what we call tumble runs or going from a plus g in two seconds to a minus g and the most we did on this was in going from a plus 9 g to a minus 9 g. Obviously a delta of 18. . . . When we first talked about doing this, I didn't think it would be possible but in doing a careful buildup we happily discovered that this was not so horrible. At plus 9 g to minus 9 g we were bouncing around a bit but it was quite tolerable.

* * *

We just finished an interesting activity out at Edwards AFB doing some weightless flying in the F–100. This was in the two-place F–100 so that we could ride in the rear seat and try various things such as eating and drinking and mechanical procedures while going through the approximately 60 second ballistic parabola that you make with a TF–100. That started at about 40,000 feet, 30 degrees dive to 25,000, picking up about 1.3 to 1.4 mach number, pull out and get headed up hill again at 25,000 and about a 50 degree or 60 degree climb angle, at which point they get a zero-g parabola over the top to about 60 degrees downhill.

You can accomplish quite a bit in the full minute in those conditions and contrary to this being a problem, I think I have finally found the element in which I belong. We have done a little previous work floating around in the cabin of the C–131 they used at Wright Field. That is even more fun yet, because you are not strapped down and can float around in the cabin doing flips, walk on the ceiling or just come floating the full length of the cabin while going through the approximately 15 seconds of weightlessness that they can maintain on their shorter parabola. That was a real ball and we get some more sessions with this machine sometime after the first of the year.[36]

Seasoned rocket experts, especially in Wernher von Braun's group, were worried early in the program over the human tolerance to noise and vibration at the tip of a missile leaving Earth's atmosphere. Biomedical experimentation during the fifties had almost, but not quite, confirmed that a man literally can be shaken to death by sympathetic vibrations induced through various harmonics upon certain organs. No one was yet sure whether the 140-decibel noise limit would be attenuated enough by the double-walled capsule and the astronaut's helmet to keep him comfortable and able to communicate.[37] In February 1960, a representative from the Army Ballistic Missile Agency at Huntsville proposed a training project in which astronauts would experience controlled noise and vibration inside a simulated Mercury capsule mounted above a Jupiter engine being static-fired. The astronauts' personal physician, William Douglas, objected vehemently and saved the astronauts from this ordeal. Internal acoustic measure-

ments in the capsules riding Big Joe and Little Joe 2, however, gave concern that aerodynamic noise at max q might blot out communications if it approached the 140-decibel limit. The astronauts decided to condition themselves to loud noises in other ways by occasionally stationing themselves near the blow-down exhausts of the wind tunnels around Langley. Carpenter, supported by the environmental control system in capsule No. 3, sat through these static noise tests and proved that communications remained satisfactory in spite of extremely loud outside noises.[38]

Other carefully controlled trials by ordeal were arranged to teach the astronauts how best to survive for a time anywhere on Earth beneath their planned orbital track. During the spring and summer of 1960, capsule egress training, and water, desert, and jungle survival courses were instituted for their benefit. So exotic and picturesque were these excursions that publicity photographs flooded the news media.[39]

Serious consideration was not given to the use of a personal parachute, with which the astronaut might bail out from his explosive side hatch, until May 1960, when Lee McMillion and Alan Shepard suggested the idea for the Mercury-Redstone flights at least. The exploits of the Air Force balloonist, Captain Joseph W. Kittinger, Jr., who had been making solo stratopheric ascents for the Air Force since 1957, were a significant factor in this reevaluation of the personal parachute. In Project Excelsior, Kittinger began a series of record-breaking sky dives. On November 16, 1959, he jumped from an open gondola at an altitude of 76,400 feet. Three weeks later, from *Excelsior II,* he bailed out at an altitude of 74,700 feet to establish a free-fall record of 55,000 feet before pulling his ripcord. STG knew of Kittinger's plans for *Excelsior III,* which he fulfilled on August 16, 1960, by diving from his balloon at 103,000 feet and falling 17 miles before opening his chute at 17,500 feet. If Kittinger could do it, so might the Mercury astronaut in case the escape tower would not jettison or both main parachutes failed on a Mercury-Redstone flight.[40]

Although supposedly the first phase of astronaut training through 1959 was to concentrate on academic studies in the eclectic new field of "space science," the astronauts did not relish book-learning at the expense of field trips, specialty assignments, and familiarization with the developing hardware. As soon as new training aids and partial simulators became available, they would make full use of them. Late in 1959, however, the only operable flight simulator was a crude "lash-up" of analog computers driving a cockpit panel display above a couch on an air-bearing floating platform at Langley. Gradually STG engineers Harold I. Johnson, Rodney F. Higgins, and George Guthrie built more sophistication into this special kind of Link trainer. By January 1960 they were calling it the Air Bearing Orbital Attitude Simulator. In use and development simultaneously through 1960, this machine slowly evolved into a major training aid called the ALFA (for "air lubricated free attitude" [or axis]) trainer. McDonnell provided a capsule shell as an egress trainer in mid-February 1960. But the most valuable and

elaborate training aids were the two McDonnell-built simulators called "procedures trainers." One for team training at the Cape and another at Langley were installed and in use by April 1960. Through long hours of practice in these procedures trainers, the astronauts "overlearned" their tasks, as Jones had recommended, so that they would act almost reflexively during their mission sequence.

During the first year of the astronaut training program, the seven pilots heard approximately 50 hours of space science lectures given primarily by senior members of the Langley Research Center. Elementary mechanics and aerodynamics made up 10 hours of this time. Formal presentations in space physics took up 12 hours. Other courses included principles of guidance and control (4 hours), navigation in space (6 hours), elements of communications (2 hours), and basic physiology (8 hours). Each astronaut spent approximately 8 hours at Morehead Planetarium at the University of North Carolina on star recognition and practicing celestial navigation.[41]

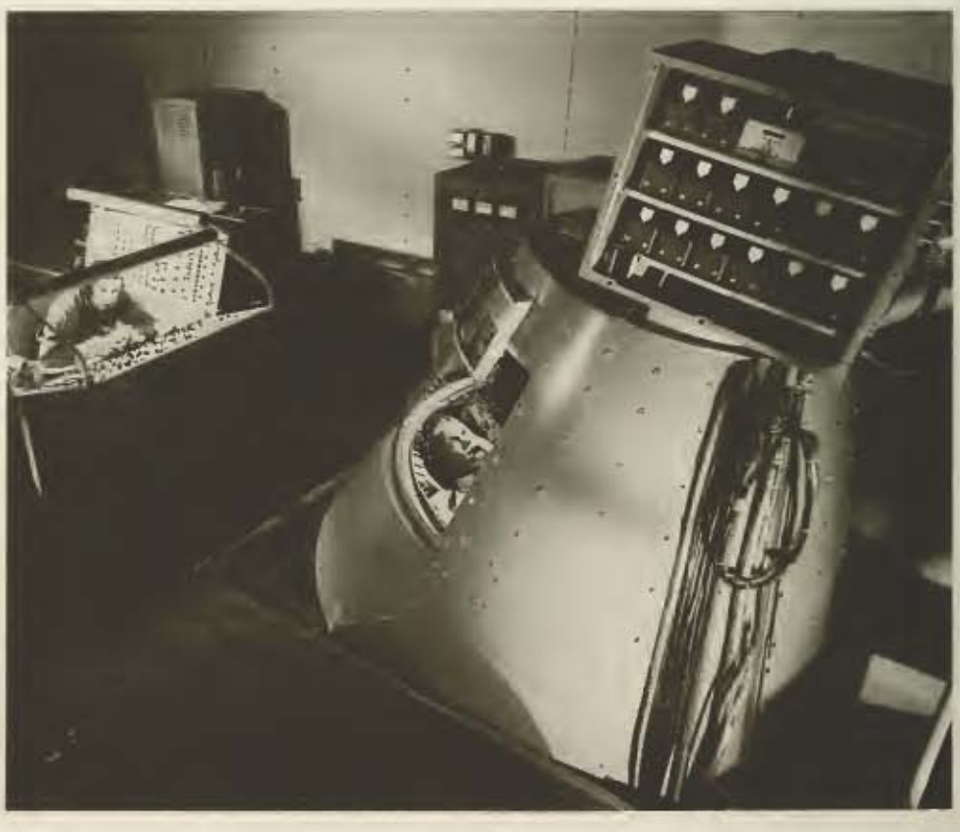
"Phase Two" of the training program, based on simulation training and engineering involvement, was to begin with the new year. But concurrent developments, individual study, and personal practice in various areas complicated the astronauts' training calendar. At the end of one full year of assignment to STG, each of the seven had spent approximately 10 days in St. Louis at the McDonnell plant; five days in San Diego at the Convair/Astronautics factory; and two days each at the Cape, at Huntsville, at Edwards Air Force Base, in El Segundo at Space Technology Laboratories and the Air Force Ballistic Missile Division, and at the Goodrich plant in Akron. Each also spent one day at the Rocketdyne factory of North American Aviation to see the engines being produced for the Atlas, another day at the AiResearch shops to meet the makers of their environmental control systems, and yet another at the Los Angeles plant of a subcontractor, Protection, Incorporated, where individual headgear was being molded.[42] These visits by the astronauts to the various industrial production lines were found to be so valuable in inspiring craftsmen and technicians at all levels to higher standards of workmanship that these personal contacts between producers and the astronaut-consumers became a regular feature of quality control programs. Grissom's simple remark on a visitation to Convair, "Do good work!" became a motto of incalculable value to every worker who heard it or shook his hand.

The astronauts also made many field trips to Government installations for familiarization with specific conditions of space flight. In addition to the training for high accelerations on the centrifuges at Johnsville, Dayton, and Pensacola, training for zero acceleration—weightlessness—was distilled from the short parabolic hops that were flown in C–131s at Wright-Patterson Air Force Base and in F–100 aircraft at the School of Aviation Medicine in San Antonio. Closer to their Langley home, the astronauts mastered scuba diving at the Naval Amphibious Base near Norfolk; at their home base swimming pool they practiced floating fully suited. Also immersions in a Langley test tank gave them the sensation of neutral buoyancy. Both at Dayton and Philadelphia the astronauts borrowed military

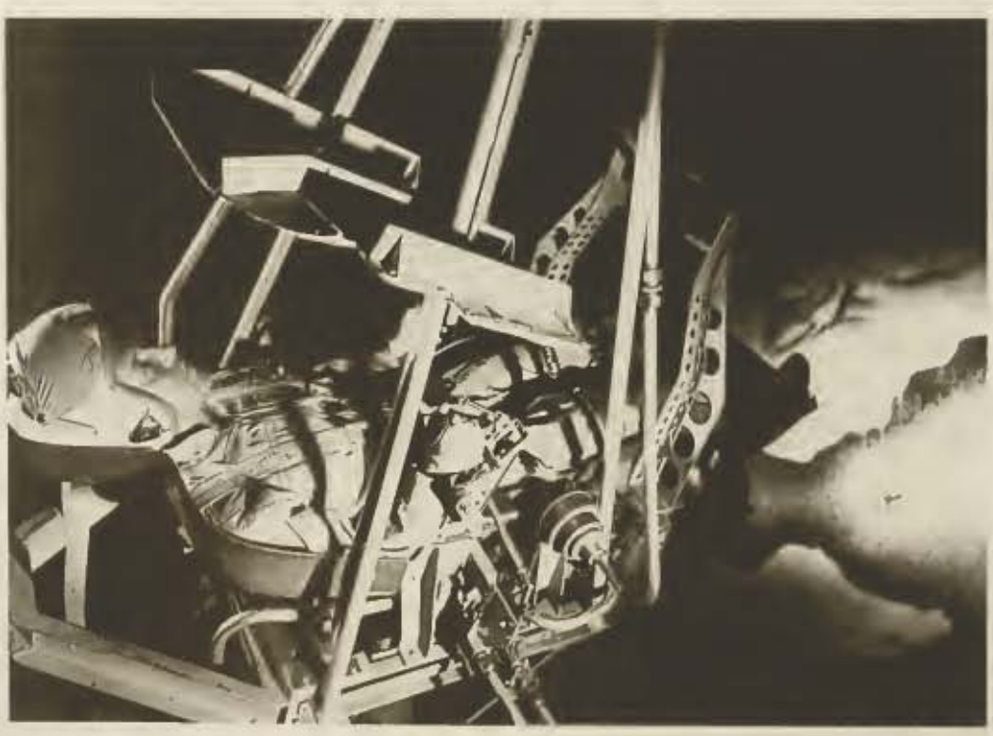
## Mercury Training Devices




*Johnsville centrifuge*



*Procedures trainer*



*ALFA trainer*

*MASTIF trainer*





*Weightlessness in C–131*

*Weightlessness in F–100F*



*Trainers and simulators have for some years been part of all flight training. In the Mercury program the normal training requirement was intensified by the new areas of sensation and orientation that man had never before experienced. Hence the astronauts underwent centrifuge runs at Johnsville, Pa., for g-force training; procedures training at Langley; ALFA training at Langley for pilotage; MASTIF training at Lewis for acquaintance with space disorientation; movement training in weightless condition in C–131 flights at Wright Air Development Center; and piloting experience with weightlessness in supersonic flights at Edwards Air Force Base.*

facilities to experience reduced ambient pressures in decompression chambers. For conditioning to withstand high heating rates, the astronauts were toasted in the Air Crew Equipment Laboratory ovens and in a "human calorimeter" at the National Institute of Mental Health at Bethesda. Two facilities at Pensacola, the "rotating room" and the "human disorientation device," provided some experience with induced vertigo. But for complex tumbling experiences, each astronaut spent some time at NASA's Lewis Center in Cleveland, in the curious test device called the "MASTIF." Finally, each man learned to know his own idiosyncrasy to high concentrations of carbon dioxide by experiments also done at Bethesda.

None of the mechanical aids for astronaut training could simulate more than a few of the conditions of space flight at a time. Even the seven Redstone ballistic flights, one planned for each astronaut, would be only partial simulations. Harold Johnson commented in February 1960 that the Redstone flights "may or may not be classified as training missions, depending on how sporting you may be." The astronauts were not only sporting in this regard, they were also chafing at delays. They suggested to Robert Gilruth that a rhesus monkey ride MR–1 so the schedule might be compressed enough to put the first chimp in orbit by the end of November.[43]

Perhaps the most impressive simulator, the whirligig called MASTIF (for Multiple Axis Space Test Inertia Facility), located at Lewis' cavernous altitude wind tunnel, was publicized far beyond its value as a training aid. Conceived in 1959 by David S. Gabriel of Lewis as a rig to test space equipment in three degrees of rotational and two degrees of linear freedom, the idea of concentric gimbaled cages was translated into hardware in the altitude wind tunnel early in 1959, when Lewis was assigned the job of testing Big Joe's attitude control system. Robert R. Miller directed the MASTIF project; Louis L. Corpas did the detail design work; and Frank Stenger developed the air-jet propulsion arrangement. Soon they had erected a tinker-toy-like rig 21 feet in diameter at its supporting yoke, capable of mounting a 3000-pound space capsule inside its three sets of gimbals, and able to turn and tumble the whole combination in three axes simultaneously at 60 noisy revolutions per minute. An early trial revved the outer cage from zero to 50 revolutions per minute in half a turn.[44]

James W. Useller, another mechanical engineer at Lewis, was first to see the potential in the MASTIF, if adapted, for astronaut training. Useller and a Lewis test pilot, Joseph S. Algranti, began taking cautious rides inside the MASTIF as soon as the controls engineers could spare it in mid-1959. They set up a formal test program for about 10 pilots and physiologists who wanted to see what rolling, pitching, and yawing at different speeds and for different lengths of time would do to a man. A thorough literature search revealed some similar late-19th-century German experiments, but Useller and Algranti proceeded to confirm a condition known as ocular nystagmus, an automatic flutter of the eyeballs induced by the acceleration of angular rotation. After extensive tests, they verified a rough

limit of tolerance at about 30 revolutions per minute in three axes; beyond this limit, even the most experienced pilots could expect to get sick.[45]

Thus, in February 1960, when the first pair of astronauts, Grissom and Shepard, arrived in Cleveland for a week's stay to test the MASTIF and their reactions to it, extensive experience had already been accumulated by other pilots. After a hard night and a frustrating morning strapped in the seat while the MASTIF was being adjusted, Shepard again stepped inside the three large gimbal cages for his second sitting but first real ride in this machine. When MASTIF finally started to spin, Shepard turned green and pressed the red "chicken switch," sounding a claxon horn as a signal to stop. To control the nausea and vertigo induced by this maniacal carrousel required dogged determination. The next day Shepard—and before the end of March all the astronauts—took examination runs at 30 revolutions per minute in all three axes and quickly learned, by using the hand controller, to activate nitrogen reaction motor brakes, to halt their rotation and bring themselves to a stop while the cages continued to spin. The confidence gained from this experience was invaluable, but one series on the MASTIF was enough. Reporters who watched a demonstration by Carpenter were vivid in their descriptions of the piercing scream, multicolored cages, and extraordinary contortions of MASTIF, billing it the ultimate in wild carnival rides.[46]

Far more important and critical was the second phase of the Johnsville centrifuge program, which began in mid-April to test much of the McDonnell hardware, including the couch and hand controller, instrument panel and full pressure suit, and the astronauts' responses to the dynamic simulation of the g profiles. An STG status report for April listed eight multiplex objectives of the ongoing centrifuge training program: (1) to test the retention by the astronaut of the straining technique and other skills developed in the August program; (2) to familiarize the astronauts with straining under reduced pressure; (3) to familiarize the astronauts with performing at high g levels in an inflated pressure suit; (4) to evaluate the couch manufactured by McDonnell Aircraft; (5) to evaluate the handcontroller developed by McDonnell; (6) to test proposed voice procedures under acceleration and reduced pressure; (7) to rehearse and evaluate the feasibility of a two-hour countdown period following astronaut insertion; and (8) to provide initial experience with Redstone acceleration patterns.[47]

With over 120 controls at his glove tips, including about 55 electrical switches, 30 fuses, and 35 mechanical levers, the astronaut had to learn a great deal regarding the monitoring and operation of these points of contact with his machine. From the prime contractor came a series of operating and maintenance manuals entitled "Service Engineering Department Reports," or "SEDRs" (pronounced "cedars"). The indoctrination manual had been replaced by a familiarization manual in the fall of 1959, and this in turn was replaced at the beginning of 1960 by SEDR No. 109, called the "Astronauts' Handbook." Although the first capsule

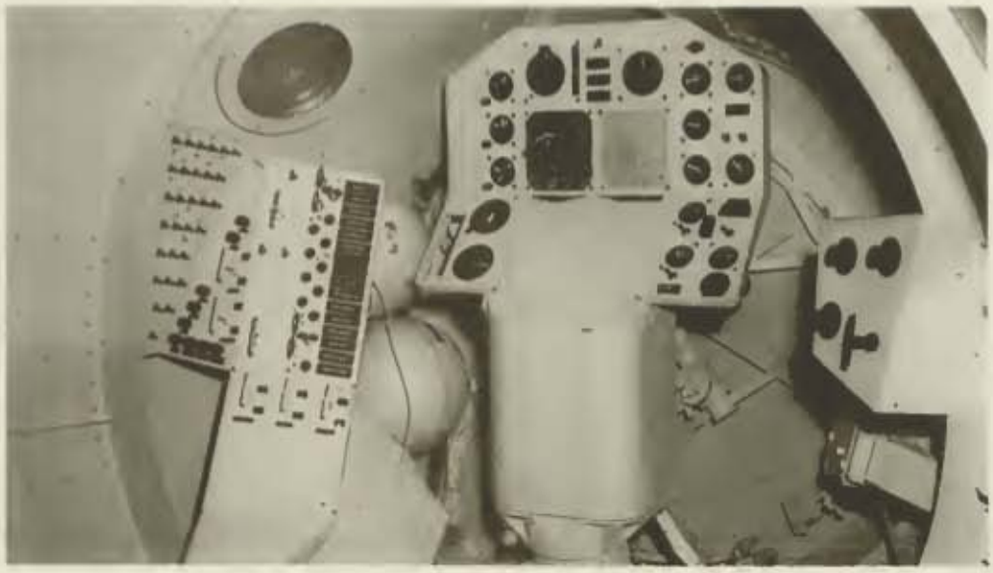
maintenance manual, SEDR No. 108, was not available until mid-year, it was not badly needed until the mass move to the Cape at that time.

The "Astronauts' Handbook" set forth operating procedures in three sections: normal, emergency, and trouble-shooting activities. The checklist for procedures envisioned in a normal orbital mission at that time included 130 items expected of the astronaut, 69 of which were part of an extensive preflight interior inspection. Under emergency operations procedures, 156 items were listed as possible pilot actions in case of equipment malfunctions. The five phases of the mission—launch, orbit, reentry, descent, and landing—each required special responses to emergencies arising during that portion of the mission. Finally, the mechanics of five major subsystems of the capsule were outlined in the trouble-shooting section and then condensed into checklists for the reaction and environmental control systems and for the electrical and communication systems. The attitude stabilization and control system checklist was promised but was not yet available.[48]

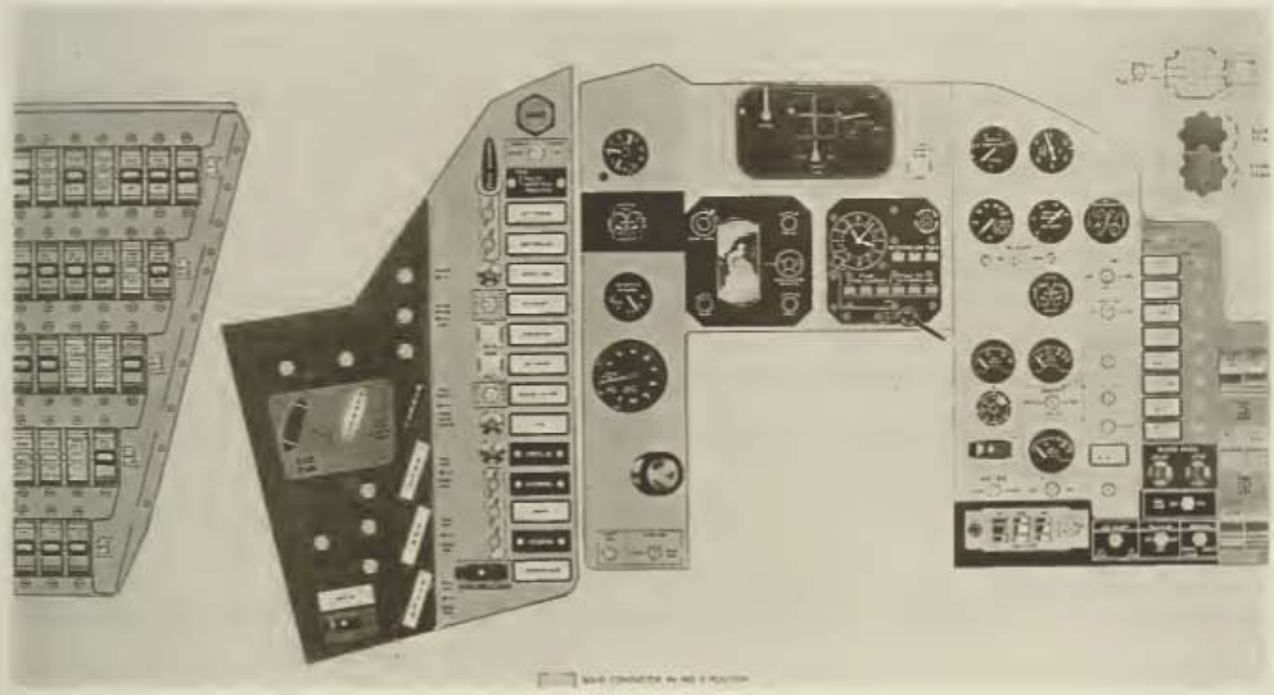
As McDonnell technical writers prepared and revised the "Astronauts' Handbook," STG's operational plans were becoming systematized through concurrent revisions of its "General Systems Information Document." Lewis R. Fisher, Donald D. Arabian, William M. Bland, Jr., and Sigurd A. Sjoberg first published this basic guide as "Project Mercury Working Paper No. 118" in March 1960 and revised it twice within the next year. They outlined the general plans for the Mercury-Atlas and Mercury-Redstone missions, including overall test objectives, flight plans, capsule design criteria, description of the capsule and systems, and the general operational plan from prelaunch phase through recovery. Specific mission directives were based on this format, and the authors of most later working papers presupposed a familiarity with "Working Paper No. 118." [49]

While John Glenn and Walter Schirra studied the interrelations of the pressurized suit and the cockpit layout, McDonnell design engineers rearranged the Mercury control panel to place all controls in a U-shaped pattern around either side and below the instruments. When an astronaut's suit was inflated, he could reach the right side and bottom of the panel with his right hand, and his left hand could reach the left side and bottom, but the center and top of the panel were inaccessible. Since Mercury gloves were thicker and heavier than those on flying suits, all controls had to be positive in operation, including guards for pushbuttons and with key handles and pull rings designed for a good grip and the application of considerable force, up to 50 pounds in some cases.

In their efforts to integrate man and machine, psychologists Jones and Voas, among others, had shown by late spring 1960 how the reliability of Mercury could be increased by the use of man's flexibility. Using the pilot as a trouble-shooter engineer in many cases could make the difference between mission failure and success. Conversely, as man's limitations became more precisely known in relation to the equipment to be used, correspondingly higher standards for the automatic systems, particularly the attitude stabilization controls, were introduced. Voas later expressed a new consensus when he said:



*Contrast in Mercury panel and console arrangement: right, the instrument positions in early 1959; below, the panels as used in Glenn's orbital flight, Feb. 20, 1962.*



The astronaut's primary job is to control the vehicle. The astronaut is not a mere passenger, but an active controller of the vehicle who performs an important and complex task which is basic to the total reliability of the mission.

System flexibility is increased by provision for the use of more than one of these [attitude control mode] systems at a time. Since the automatic reaction jets and the manual reaction jets are completely independent, it is possible for the man to exercise control through the manual jets while the auto-pilot is exercising control through the automatic jets. One occasion for use of both control systems would be in maneuvering in orbit when the astronaut desires to let the autopilot control two axes such as roll and pitch while he takes control in yaw.[50]

Meanwhile Jones and the human factors engineers at McDonnell were determining more ways in which man could back up other automatic malfunctions through their "failure task analysis." Using the failure mode predictions from

the design engineers' work on the reliability program, they elaborated "in detail the probable sensory output characteristics of the failure, the corrective responses required by the astronaut or ground monitor, and the failure effect." [51]

Jones' human-factors team worked closely with McDonnell's Mercury reliability experts, Walter A. Harmon and Eugene A. Kunznick. They in turn allied themselves with another McDonnell crew employed on a special check of the Mercury reliability program instigated by NASA Headquarters. Programmers at McDonnell coded on punch cards all probable systemic failures; by June 1960 they had assembled massive computer printouts that detailed corrective actions an astronaut could take in case the robots should go wrong. They found that over a third of such failures would not show up on instruments or through warning lights, but could be detected through symptoms presenting unusual sights, sounds, smells, or vibrations. As many as 18 different failures, however, might show the same set of multiple cues, so the work of categorizing and organizing these data required another full year. Preliminary results from these cooperative studies helped early to isolate malfunctions that needed new indicators, to rank the frequency of instrument use, and to shape the training program. Efforts to predict the total system reliability by this evaluation intensified the debate over the "numbers game." [52]

## Looking Over Mercury and Beyond

In March and April 1960, NASA scored two spectacular triumphs by using the Air Force's Thor-Able booster combination to launch *Pioneer V* and *Tiros I*. The former was a highly successful instrumented probe to explore the space between the orbits of Earth and Venus. Launched on March 11, *Pioneer V* established a new telecommunications record of 22.5 million miles by the end of June and returned a bonanza of data on solar flares, particle energies and distribution, and magnetic field phenomena in translunar space. The initial Tiros weather satellite, sent up on April 1, transmitted the first global cloud-coverage photographs from a circular orbit 450 miles high, thereby inaugurating a new age for meteorology. The request for implementation of NASA's 10-year plan presented to Congress on January 20 seemed off to a good start. An extensive congressional "Review of the Space Program" put Mercury, even in the context of NASA's present programs, in perspective as a relatively minor part of the civilian space agency's activities. In terms of NASA's plans for the future or of the total military-civilian space program already in action, Project Mercury was hardly more than "an important first step in our manned exploration of space." [53]

Through the winter and spring of 1960, the big event toward which Mercury watchers looked with most anticipation was the launch of the first Atlas vehicle topped by a McDonnell capsule. Immediately after Big Joe, Gilruth had requested the Ballistic Missile Division to fly another Atlas along a Big Joe-type

trajectory to qualify the McDonnell capsule for launch and reentry from a circular orbit roughly 105 miles high. At the beginning of 1960, it still had looked as though this could be accomplished by the end of May. A semifinal Defense Department operations plan outlining the support tasks of a dozen different military commands was under intensive study during this period. Serious reappraisals of schedule requirements and alternatives were underway in many areas, most of which threatened to delay the start of the qualification flight. By the end of January it was obvious that the payload, McDonnell's capsule No. 6, for the first Mercury-Atlas launch (MA–1) would not be ready soon enough.[54]

The bottleneck was the production line. Back in October 1959, when a letter amendment to the prime contract for six additional Mercury capsules was being processed, McDonnell had estimated it could deliver capsule No. 1 by the end of November. To be sure, this would be a stripped model suitable only for an off-the-pad or beach-abort mission, but at that time it looked as if the firing date for this first qualification test could be set for the last day of 1959. It then seemed that capsule No. 2, allocated to the first Mercury-Redstone flight, also could be delivered before the end of the year and shot about March 20, 1960. The sixth capsule, farther down McDonnell's production line, originally was allotted to the first Mercury-Atlas flight. It was barely framed, but McDonnell had hoped to deliver it by the end of February for a tentative launch date in mid-May. While STG was immersed in the Little Joe program, however, the production managers at McDonnell became aware that actual final assembly of the first capsules and equipment would take far more time than anticipated. On November 3, 1959, Sherwood L. Butler, the procurement officer at Langley, had notified NASA Headquarters that capsules Nos. 1 and 2 each would be delayed a month; No. 6 might be expected by the end of February.[55]

What, precisely, was causing these delays? Logan T. MacMillan, Edward M. Flesh, Yardley, and Dubusker of McDonnell felt constrained to answer as the pressure for delivery increased—as did certain conditions that obviously needed to be corrected. Incorporating the smallest changes during the final assembly of the first six capsules required many hours of disassembly, reassembly, and rechecking. Only one or two men at most could work in the confined space of the pressure vessel's interior, and rising standards of quality control imposed by McDonnell, STG, and resident Navy inspectors required much reworking.

For example, on the first shift on January 6, 1960, J. E. Miller, the McDonnell inspector on the floor at the time, logged in his record book a local cause of delay:

> Insp. discontinued all work on Cap. #1 this A.M. until the filthy condition of the capsule was cleaned up. A meeting of Prod. Supervision was called by Insp. & Engr., was asked to set [sic] in. Quality control was main subject & all agreed to extend more effort toward better quality control although Prod. did not think they could do much better than what was already being done.[56]

The next week at a capsule coordination meeting in St. Louis, Purser and

MacMillan, Yardley and Faget persuaded Robert Gilruth to save MA–1 by swapping capsule No. 6 for capsule No. 4, which had been scheduled for a static firing on the Redstone. Number 4 should be tidied up as quickly as possible and shipped to Langley by the end of the month. Only a structural shell, this first delivered piece of production hardware did include the exterior shingles, heatshield, landing and recovery gear, missile adapter-ring, retropackage and straps, with dummy retros and live posigrades. STG undertook to install Big Joe-type instrumentation and sequencing for its rescheduled use on the first Mercury-Atlas flight. The plan was to return the capsule to McDonnell by April 1 for final shingle fittings and adapter matings, then ship the completed capsule to the Cape by mid-April. At the same time it was decided to eliminate the flotation bags, which had proved to be too delicate to last long in the open ocean, from all capsules and to keep the configuration of capsules Nos. 5 and 7 unchanged in hope of making possible an earlier manned shot. Problems with the afterbody shingles and with the erosion of the window by the blast of the escape rocket were among a number left unsettled.[57]

As costs of solutions to these kinds of technological and training problems rose, NASA administrators appeared more frequently before Congressional committees and admitted their growing concern with manned space flight, as opposed to other space activities. T. Keith Glennan requested $23 million supplemental appropriation to the fiscal 1960 NASA budget of $500.6 million and justified $19 million of that extra sum on the basis of the urgent technological demands of Project Mercury. "It would be no exaggeration to say that the immediate focus of the U.S. space program is upon this project," stated Glennan.[58]

## Management Learns Its Limits

The astronauts were not alone in their need to become in some sense machine-rated. The managers of Mercury, both the civil servants and the contractors, had found truth in the maxim of industrial management that short-term estimates of accomplishment are nearly always overestimated. Mercury, like virtually all contractual development programs, entailed inherent technical and administrative difficulties impossible to foresee. A corollary to the rule of short-term estimates, namely that long-term predictions of accomplishments are very often underestimated, offered little solace at this stage of the development of Project Mercury. In its fifth status report at the end of January 1960, the Space Task Group related to Headquarters some of the lessons learned during its first year of contractual operations:

> A new capsule delivery schedule has recently been indicated by McDonnell to reflect a delay in delivery of over 3 months in the early capsules. This revision was made necessary by a realistic appraisal of progress to date. Although various proposals for improving the situation have been considered, there does not seem to be any practical avenue open at this time for effecting any worthwhile change.

> Because of these delays and the fact that it has not been possible to substantiate the shingle structure adequately on the ground, it has been decided to cancel the vibration program on capsule No. 4 and instead to fit this capsule with an absolute minimum of equipment and instrumentation and to fire it on an Atlas as MA–1 . . . at the earliest practicable date.[59]

Gilruth, Charles J. Donlan, and their younger associates in STG grew older rapidly during their first 15 months as a contracting agency. Gradually attaining more autonomy, the Space Task Group still expected eventually to move to Beltsville, Maryland. But in February NASA Headquarters made clear its intention not to move STG until Project Mercury was essentially completed. Relations with the Langley Research Center, STG's parent organization, improved markedly with better organizational arrangements, such as job order procedures, and with the growth of STG's own administrative staff. Close working exchanges still prevailed in many areas, especially with the Langley shopmen under Jack A. Kinzler providing technical services. But on STG's first birthday, only two out of Langley's 12 applied research divisions could still say with regard to Mercury that "there is as much to be done as has been done." [60]

The Pilotless Aircraft Research Division (PARD), renamed the Applied Materials and Physics Division at the end of 1959, and the Instrument Research Division were still most actively supporting Mercury.

During STG's infant year, overall Langley support amounted to well over 100 separate preliminary data releases, contributed by more than 325 professional people, and costing approximately $1.9 million of Langley's own appropriations. STG's personnel complement in January 1960 was climbing above 500; the total cost of the prime contract with McDonnell, already modified in about 120 particulars, was approaching $70 million and rising. At the same time, McDonnell estimated that more than half its total effort on Project Mercury was still in engineering development; a third of its effort was on actual production; and about 10 percent was on tooling. According to McDonnell's assistant contract manager, the overall weighted percentage of contract completion was just below 60 percent.[61]

The magnitude of monitoring a contract of this size was reflected in another reorganization of the Space Task Group in mid-January. Formalized in the new block chart were the personnel office under Burney H. Goodwin, a budget and finance office under J. P. Donovan, a procurement and supply office under Glenn F. Bailey, and an administrative services office under Guy W. Boswick, Jr. STG simplified its three line divisions by making James A. Chamberlin chief of its "Engineering Division" instead of the "Engineering and Contract Administration Division." Under Chamberlin, Andre J. Meyer, Jr., and Norman F. Smith served as assistant chief and executive engineer, respectively. In Faget's Flight Systems Division, Robert O. Piland and J. T. Markley were confirmed in their posts as assistant chief and executive engineer.

At this time Faget unofficially set Robert Piland to work considering advanced

vehicles suitable for a circumlunar space flight. This soft-spoken Virginian had turned from mathematics to aeronautical engineering in 1947 and had served as technical assistant to James T. Killian and the President's Science Advisory Committee during 1958. Technically able and politically experienced, Piland directed the circumlunar pilot studies for four months before authorization for an advanced vehicle team on May 25, 1960, formally added eight other senior STG engineers to look to the future beyond Mercury.[62]

Robert Piland also learned something from his older brother, Joseph V. Piland, assistant head of the contracts and scheduling office, who had evolved from a mechanical engineer into a contract administrator. Joseph Piland was instrumental in smoothing STG's formal relationships with its industrial contractors. His counterpart in McDonnell's organization was C. F. Picard, and together they had now to supervise over 50 subcontractors and over 5000 sub-subcontractors.

Charles Mathews' Operations Division was in a state of flux as he and Walter C. Williams shuffled men and positions in preparation for manned operations. Christopher C. Kraft, Jr., and Chris C. Critzos stayed put, while G. Merritt Preston went to the Cape and Scott H. Simpkinson was sent to St. Louis to help expedite matters at McDonnell. Other names on the STG organization chart of January 11, 1960, filled staff positions alongside Purser, Kenneth S. Kleinknecht, and Martin A. Byrnes. Another assistant to the director was Raymond L. Zavasky; heading the technical services liaison with Langley was Kinzler. The military officers originally assigned to STG as liaison remained aboard and active. They were Colonel Keith G. Lindell of the Air Force, who doubled as head of the astronaut and training section; Lieutenant Colonel Martin L. Raines of the Army; and Commander Paul L. Havenstein of the Navy. Even Langley Research Center, across the field, had its liaison man on STG's staff: W. Kemble Johnson.[63]

Beginning in January 1960, plans were made to integrate the astronaut with a flight-control team as well as with his machine. Team training of the remote-site ground crews required an extensive familiarization and orientation program. The initial proposal for training these teams began with an admonition:

> It is essential that the training of the flight control personnel be closely integrated with that of the astronaut's. As long as the astronaut is conscious all ground commands must be executed through or with the concurrence of the pilot. To be effective, the pilot and the ground crew must work as a closely knit team. An efficient system is dependent upon adequate team training and development of mutual confidence.[64]

In preparing to train and integrate the flight-control team for final operations, Walter Williams first discussed the problem with Kurt H. Debus, the Director of ABMA's Missile Firing Laboratory, and Major General Donald N. Yates, the Defense Department's representative and Commander of the Air Force Missile Test Center at Patrick Air Force Base, near Cape Canaveral. Manned missile

operations were as new to them as to him, so on January 18, Williams wrote letters to each of these gentlemen formally proposing the establishment of new coordination committees for the upcoming flight tests. NASA Headquarters meanwhile had appointed another Air Force missile expert, Major General Don R. Ostrander, as Director of an Office of Launch Vehicles. His appointment, it was felt, would help interservice cooperation and relieve Silverstein of management responsibility for rocket development.[65]

In February Mathews and Williams organized a Launch Operations Branch within STG's Operations Division under Preston at the Cape. Then they specified the duties, organization, and responsibilities of the Mercury launch coordination office. Approaching a phase of heavy operational activity, different in kind as well as degree from Edwards and Wallops Island field operations, Williams and Mathews appointed Christopher Kraft as flight director, Stanley White as chief flight surgeon, Merritt Preston as launch operations manager, and Scott Simpkinson as capsule operations manager. By early March, 32 other position titles for ground operations—in the Mercury Control Center, in the blockhouse, at Atlantic Missile Range Central Control, and in the launch pad area—were specified. Capsule engineers at the Cape published quickly a thick "Manual for Launch Operations," which indicated their readiness to assume responsibility for launch operations. Williams also asked Destroyer Flotilla Four to plan for the recovery of MA–1 toward the end of May.[66]

If Debus and Yates were somewhat chagrined by the forceful speed and decision exhibited by Williams and Mathews in setting NASA firmly in control of launching operations, they were not alone in worrying about the future. Within other divisions of the Space Task Group there was also some worry lest the operations division should monopolize participation in the payoff phase of Project Mercury. William Bland, for instance, wrote a memo to Maxime Faget early in March urging that "the specialists who have matured with Project Mercury" not be diverted to advanced vehicular planning before getting a chance to prove in flight the systems they had designed:

> As Project Mercury matures, the total workload with the Space Task Group will increase with the greatest portion of the load carried by the operations division. This change in relative work does not mean that personnel of the flight systems division should decrease their participation in the project. Actually personnel of the flight systems division, at this particular time, have a much wider and deeper range of experience in preparations for launchings, in launchings of rocket vehicles, and in flight data analysis than the Mercury launch personnel (NASA and MAC). This experience in detailed knowledge which was collected during the Little Joe and Big Joe flight programs, the beach abort tests, the different system development programs (such as those conducted on escape motors, pyrotechnics, parachutes, drogue chutes, controls, etc.), and in the development of individual components which make up the capsule system, must be available to the Space Task Group organization conducting launch operations in order to insure direct approach to *successful launchings.*[67]

Bland expressed to Faget his concern about the possibility of being preempted from participation in Mercury operations. Faget, restlessly pursuing his first loves of conceptual design and initial development, first for Mercury and now for something soon to be called "Apollo," was in danger of losing the support of some of his lieutenants unless the Flight Systems Division got some role in the flying of their systems.

Part of this disaffection had been precipitated by a major meeting regarding the Mercury network, held on February 9 at Langley. Ostensibly this meeting was to discuss the operational organization, maintenance and operations training, and communications for the network. About 30 men from the Air Force, Navy, Western Electric, Bendix Radio, the oceanic missile ranges, and the Tracking Unit at Langley met with Williams, Mathews, Kraft, and John D. Hodge, but no representative of the Flight Systems Division was present. A week later Gilruth appointed the flight controllers and set C. Frederick Matthews, a Canadian whose name was often confused with that of his chief, Charles W. Mathews, in charge of coordinating the ground crew training programs. Walter Williams saw this as a full time job in itself. By the first of March flight controller indoctrination and training plans were underway, and Philco contractors and medical monitors were being briefed for a larger role at various ground sites whenever their training should warrant.[68]

In mid-March Faget confronted another problem in machine-rating his technicians when he received another technical complaint, this one from William A. Petynia, a conscientious engineer he had assigned to watch complete systems tests of capsule No. 1. Petynia had been working with McDonnell project engineer A. M. Paolini since June 1959, preparing capsule No. 1 for the beach-abort launch from Wallops. But the complicated, specialized knowledge required to do a faultless job seemed to Petynia to be overwhelming by the spring of 1960:

> To determine the "overall picture" is not difficult, but I found additional effort was required to be in a position to even partially understand capsule systems. I do not mean to become a specialist in each of the capsule systems, but I wanted to be able to recognize and understand problems and their relationship with the flight.
>
> The flight systems capsule engineer is the one person in the test organization who clearly understands the flight test objectives and the performance of the hardware in order to fulfill them. This I think is important! However, I think that due to the complexity of the capsule, the engineer cannot hope to become familiar with the hardware to any great degree in the short period before CST [Capsule Systems Test]. I believe that training classes for the engineers [should] be started immediately under MAC's supervision.[69]

Petynia's awareness of the necessity to machine-rate himself so he could do an adequate job of inspection was one individual manifestation within STG of the problem of getting all the million or so people involved to do a perfect job in order to man-rate all the machines. From the highest level to the lowest,

supervisors sought better methods to inspire the men at work on Mercury to make the quest for reliability a personal matter.

One of the methods used to good effect was identification, both of parts and of workers in the project. The Redstone managers had adopted in 1959 a seal showing the anthropomorphic god Mercury in winged cap and boots bearing a missile and vaulting Earth. Atlas managers eventually selected the alchemical and astrological symbol for Mercury, enclosing a blue "R" for reliability, as their identifying label for Mercury-Atlas components and laborers. On personnel badges, these marks of distinction meant a record of highest performance, but on hardware these decals signified a test record that came closest to the nominal design desiderata. Machines or components that performed too well in certain respects were suspect as possible troublemakers in other respects for the future.[70]

The astronauts were now making periodic appearances along the production lines at McDonnell, Chrysler, Convair/Astronautics, and elsewhere to encourage the highest standards of craftsmanship among even apprentices or semiskilled workers handling or processing any components that bore the Mercury decal. Having shaken the hand of one of the pilots whose life depended on their work, the factory workers presumably would treat with the greatest care and tenderness the parts then still in their hands.

Credit for having first worked out the guidelines for a coherent plan to machine-rate everybody probably should go to Bernhard A. Hohmann and Ernst R. Letsch of Space Technology Laboratories (STL) and later of Aerospace Corporation. Together with Major General Osmond J. Ritland, former test pilot in command of the Air Force Ballistic Missile Division, Hohmann assured the astronauts that their interests would never be sacrificed. Hohmann's study of the "General Aspects of the Pilot Safety Program for Project Mercury Atlas Boosters" analyzed the differences between the ideas of reliability, quality control, and quality assurance before synthesizing them in a specific program adaptable to other areas of Mercury development. Hohmann combined the approaches of the mathematicians and systems engineers at STL with the viewpoints of production, inspection, and test engineers at Convair/Astronautics, Rocketdyne, and elsewhere.[71] But some of the compromises he recommended, such as choosing most nominal instead of highest performance parts to assure a higher level of final quality, were appropriated only gradually by NASA and STG.

Upgrading the intensity of quality control over raw materials, of inspections and tests of systems integration in the plant, and of the requirements for a complete vehicle at the time of the "factory rollout" were significant parts of the pilot safety program. In the final analysis for flight readiness, a Flight Safety Review Board, patterned on Air Force practice, should take the technical responsibility for certifying the booster to be man-rated.[72] Even after all these precautions there was always going to be an element of doubt. Procedural principles on paper would require two more years—and at least five flight experiments—to become realized in practice and working habits.

## Is Perfect Reliability Possible?

At NASA Headquarters in Washington on February 29, 1960, the high-level debate over the meticulous versus the statistical approach to reliability was fervently renewed. NASA, STG, and McDonnell representatives that day met in conference to decide what weight to give the "numbers game" in their own confidential estimates of readiness. Gilruth, Donlan, and their chief of reliability, John C. French, defended STG's practical procedures against the theoretical approach of Nicholas E. Golovin, Landis S. Gephart, and Catherine D. Hock. The third revision of McDonnell's reliability program was delivered by Eugene Kunznick, who also outlined the particulars of the prime contractor's quality control measures. Walter Williams presented STG's latest views on operational flight safety, and STG generally endorsed McDonnell's reliability program review as its own. But neither Richard E. Horner nor Golovin was satisfied that the pains being taken by STG and McDonnell were sufficient or thorough enough.[73]

A new Division of Life Sciences Programs was created in March at NASA Headquarters, with Clark T. Randt, a neurosurgeon from Cleveland, as its director. Part of this division's purpose was to ensure machine-rated men for the future of manned space flights. Earlier in the year an Air Force aeromedical leader, Brigadier General Don D. Flickinger, reported to NASA and STG on his recent trip to Russia and on the opinions he had formed about Soviet progress toward manned space flight. Flickinger estimated that the Soviets would attempt without prior announcement to orbit a two-man laboratory about mid-year. The American astronauts were "anxious to do anything possible to speed things up." [74]

But the hardware was simply not yet hard enough or wearable enough for the insiders to get deeply excited about beating the Russians into space. Just after capsule No. 4 arrived at Langley, Purser went to look at it and reported to Gilruth:

> Although there are evidences of careless workmanship, I don't think it is too much worse than standard aircraft practice. Also, most of the bumps, patches, etc., seem to be on the unpressurized part of the structure. It was also mentioned by one of the boys that Capsule 4 was never intended as a flight vehicle, but only as a vibration-and-static test article; this can account for a lot of the errors. While many of the bad spots could be caught by inspection and corrected, a lot are non-fixable except by junking a capsule. These can only be avoided by inspiring in some way, better workmanship. I would suggest documenting the bad spots on Capsule 4 and then having a good inspection by STG people of the flight capsules now on the line. This could be repeated in 6 to 8 weeks to catch the next batch and probably would cure the troubles.[75]

After the late February meeting on reliability in Washington, a great deal of ferment was evident in systems testing, quality control, engineering inspection, and a new order of reliability testing. At the McDonnell factory, Robert L. Seat, who together with George Waldram had drawn up the first capsule systems test plan, began to clarify the differences between acceptable aircraft qualification test practices and spacecraft systems integration and reliability tests.

In early March, STG sent a delegation to Huntsville and Detroit for the latest word on reliability program upgrading at ABMA and at Chrysler. Joachim P. Kuettner, Eugene J. Buhmann, and von Braun's deputy, Eberhard F. M. Rees, conducted tours and arranged presentations for March 7 and 8. The next day at Chrysler's missile plant in Michigan, C. A. Brady, Bernard J. Meldrum, and L. L. Baker presented a similar review, which apparently satisfied their visitors from STG that the Redstones for Mercury could be trusted.[76]

Through March and April the pressure on McDonnell to deliver the goods unfinished and yet with perfect reliability records became so acute that James S. McDonnell and his board of directors in St. Louis appointed their factory manager, Walter F. Burke, to meet and satisfy that pressure. Burke, already a company vice-president, was named general manager for Project Mercury. Logan MacMillan remained as "company-wide project manager" for McDonnell, but the addition of Burke signified the scale of the growth in size and scope of the Mercury contract.[77]

McDonnell would have been remiss if it had not responded at the highest level to NASA's pressure. All the aerospace companies knew that Faget and Robert Piland were traveling around the country during April 1960 presenting their preliminary ideas and plans for "advanced vehicular" space flight programs to other members of the NASA family. Technical speculation was rife over how best to accomplish manned circumlunar flight. Other corporate giants, including Grumman and Convair/Astronautics, were competing for snippets of knowledge about what was going on in these confidential deliberations within NASA. But James Chamberlin, among others, was wondering, as he watched the difficulties in manufacturing and ground testing McDonnell's first capsules, difficulties particularly acute with the sequence and wiring systems, whether speculation about spacecraft ten years hence was legitimate, profitable, or even necessary.[78]

While uneasiness over reliability was interminable, there were limits—practical, political, and social—to the amount of time that could be sacrificed for quality assurance. Decisions had to be made and, after close calculation, risks taken. Abe Silverstein at NASA Headquarters intervened at this point, deciding to short-circuit a duplicate set of prelaunch checkout operations. On March 29, two weeks after President Eisenhower had ordered that the big new NASA facility at Huntsville should be called the George C. Marshall Space Flight Center, Silverstein wrote von Braun a lengthy letter of explanation:

> I have just completed an extensive reexamination of all Mercury schedules, from the point of view of expediting the entire Mercury program. As a result of this reexamination, I have arrived at the conclusion that it is of utmost importance to obtain flight performance data of certain critical components of the Mercury systems at the earliest possible time. More specifically, it is important to initiate the Mercury-Redstone flights as soon as possible in order to obtain inflight evaluations of the Mercury capsules at an early date.
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> * * *

> A detailed study of the checkout programs at McDonnell, Huntsville, and Cape Canaveral has revealed that there exists a great deal of duplication; in particular all the booster capsule compatibility checks are performed both at Huntsville and at the Cape. The only unique tests scheduled to be made at Huntsville (on MR–1 only) is a vibration and noise test to be performed during the booster static firing.
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>
> In view of these facts, it appears that the capsule prelaunch operations at Huntsville are no longer required. I have therefore directed that the Mercury capsules assigned to the Redstone program be shipped from St. Louis directly to Cape Canaveral, thereby gaining approximately two months in the launch schedule. I suggest that all parties concerned meet at NASA headquarters in Washington in the near future to discuss detailed arrangements necessitated by this new procedure.[79]

But a week later Kuettner persuaded Silverstein to relent on this decision and to agree to a compromise: the capsule for MR–1 would be shipped to Huntsville for a much shorter period to test the mating and to check on problems of radio frequency and electrical compatibility. Silverstein now wrote von Braun a letter of appreciation for reducing the Huntsville checkout time "from 8 weeks to 16 days, so that the Mercury-Redstone program can proceed as rapidly as possible." Shortly thereafter, Silverstein also learned that the Air Force Chief of Staff, General Thomas D. White, was reaffirming in strong language to his troops that the Air Force should cooperate with NASA "to the very limit of our ability, and even beyond it to the extent of some risk to our own programs" if that were necessary.[80]

Scheduling problems continued, becoming acute toward the end of June, when the schedules for qualification flight tests were recognized to have slipped by at least six months. Complete capsule system testing seemed to require new organization, new procedures, and new ground test equipment. Purser filed a note for himself on a major meeting on June 27–28, attended by Silverstein and Director Harry J. Goett of Goddard, wherein the top technical managers of Mercury and STG began to admit that perfect reliability is indeed impossible. Quality control and reliability testing must be raised to a new level of effort, and not only man and machine but man-rating and machine-rating processes must be integrated, reflected Purser.

> One of the major problems facing Mercury management is the conflict between a real desire to meet schedules and the feeling of need for extensive ground tests. The MAC capsule systems tests are not meeting this need since they were not intended for this purpose and since the pressure of time sometimes forces bypassing of some details (to be caught later at the Cape). Further, there has not been time available (or taken) on the part of MAC to study and update the CST procedures and SEDR's. It was concluded that a group (mostly MAC effort) should be set up to review and update the CST and SEDR procedures. It is also firm that no details will be bypassed in the Cape checkout without the express approval of STG management.
>
> * * *

> There was considerable discussion of a proposal to eliminate the unmanned orbital shots on the basis that the systems could be qualified in unmanned and manned ballistic shots and that the presence of the man would reduce the possibility of failure in the first orbital shots and thus reduce chances for a consequent delay in the program . . . *it was decided* to not change [sic] the program now but to keep the door open and reconsider when MA–5 and MA–6 are closer. Since the astronauts have expressed considerable interest in this proposal STG management is to discuss the above decision with them.[81]

Just before the reliability meeting in February, the Task Group had received welcome news of improving Atlas reliability as a result of more series-D firings since Big Joe. Already in mid-February STG had assigned a rough reliability coefficient of 75 percent, based on virtually perfect ignition and running of the engines and excellent performance from airborne and ground guidance systems in recent tests. Studies of the Abort Sensing and Implementation System for Mercury indicated that 13 of 43 series-D flights would have been aborted had the ASIS been aboard; only one of those 13 would have been terminated unnecessarily by the system's sensors.[82] Hopes were high, therefore, that whenever qualification flight tests should begin with Mercury-Atlas No. 1 (MA–1), they would follow each other rapidly at monthly intervals.

While Edison M. Fields and Sigurd A. Sjoberg of STG began the arrangements for adapting Atlas 50–D to capsule No. 4 for the MA–1 flight, Hohmann's engineers at STL, including James W. McCurry and Ernst Letsch, together with a reliability team supporting Philip E. Culbertson at Convair/Astronautics, were all warning of the consequences from the predicted increase in capsule weight. Guidance and trajectory equations, dependent upon moments of inertia, center of gravity, and a gross capsule weight now over 3750 pounds at launch, had to be recalculated.[83]

The first Mercury-Atlas test flight was to be virtually a repeat of Big Joe, with the significant difference that a McDonnell capsule was to be qualified rather than a NASA model demonstrated. The primary objectives for MA–1 were also similar to those for Big Joe: to determine the integrity and stability of the McDonnell-built structure and to measure heating rates on the afterbody shingles during a critical abort and reentry.

MA–2, scheduled for September, should test the integrity and flight dynamics of McDonnell capsule No. 6 during a simulated nominal reentry from orbit. Having decided to change the materials and increase the thickness of the outer shingles on both the conical and the cylindrical section of the capsule, STG had added 63 more pounds by specifying the use of René 41 nickel alloy .016-inch thick on the conical section and 12 beryllium panels .22-inch thick on the cylindrical afterbody. The reinstatement of the impact bag and the drogue chute, plus the addition of insulation, a super sarah beacon, and heavier batteries, raised the estimated weight of the orbital configuration of the capsule to 3000 pounds.[84]

Feverish, if not frantic, work and worry went into these decisions, beginning

as soon as capsule No. 4 arrived at Langley. But Bond, Fields, and Meyer, taking up where they had left off with Big Joe, ran a taut project through mid-April; they "pessimistically and therefore," they believed, "realistically" estimated again that they would see this rocket's red glare on July 4, 1960. Caldwell C. Johnson and Jack Kinzler supervised the polishing of capsule No. 4 as they had for the Big Joe payload.

But summer arrived, and Chamberlin reported continual capsule delivery delays at the weekly STG capsule review board meetings. The slowdown and stretchout of the flight-test schedule became ever more vexing and costly. Meanwhile NASA Headquarters began to centralize and simplify its launch operations under Ostrander, leaving to Silverstein preflight worries and responsibility for Mercury boosters only. Warren North justified a $7 million overrun on the prime contract for which STG was seeking approval:

> This overrun was, of course, anticipated. A major factor involved in the McDonnell overrun is the high level of engineering required in support of the testing program. McDonnell previously planned to reduce their engineering effort in early 1960. However, because of the increased scope of the testing program and the capsule changes, these engineering reductions have not taken place; in fact, in their last monthly report, McDonnell shows their engineering head count at 913 and increasing. The procurement overrun is due primarily to subcontract overruns at Bell, AiResearch, Collins, Radioplane, and Perkin-Elmer.[85]

To try to speed things up and to keep safety paramount, Silverstein instituted biweekly meetings at NASA Headquarters with Walter Burke of McDonnell and Gilruth of STG. Both quality control and urgency militated against keeping cost ceilings permanent. They also militated against the schedule. Glennan had directed that no flight schedule changes should be made without his personal explicit approval. But the technological realities of ensuring highest technical performance and STG's priority concern for the orbital objectives of Mercury, rather than for suborbital man-in-space, allowed the first Mercury-Redstone flights to slip past, or at least alongside, the Mercury-Atlas qualification flights.

## Head and Hands of NASA

During March and April, Administrator Glennan called on the Space Task Group, as well as all of NASA, to conduct a self-appraisal of NASA's contracting policy and industrial relations. A firm of management consultants, McKinsey and Company, had entered into a contract with NASA on February 26, 1960, for a comprehensive study of how NASA should utilize industry and private institutions, how it could improve its utilization of its own research capability, and what the extent and manner of sharing responsibility and authority between Government and industry actually was.[86]

The Space Task Group responded with a self-analysis which listed the major

elements of Project Mercury, gave an explanation of the major tasks involved, and discussed the reasons for performing each task within NASA or on contract. The preliminary draft of this information divided the tasks of the Task Group into three subsystems—the capsule, boosters, and tracking and communications—each of which was further subdivided into elements and tasks. When the representative of McKinsey and Company visited STG on April 19 to discuss the working methods used in the conduct of Project Mercury, he was briefed by Purser, Zavasky, Mathews, and Bond, and provided with documents tabulating the distribution of STG personnel man-years, associated costs, and "R and D" fundings. Although McKinsey's final report did not appear until October, the Task Group finished its part of the self-examination in May. STG learned from this exercise that it had shifted from research and development into almost exclusively development activities.[87]

At the highest level within NASA Glennan and associates recognized, as Robert Rosholt has described it, that the "opportunity to make comprehensive changes in NASA's organization and procedures would not exist too much longer, i.e., bureaucratic hardening of the arteries would make change more and more difficult as the agency became older and larger." The final McKinsey report appeared to endorse the "integrated project management team" approach used by STG. The Space Task Group, however, was still only a semi-independent subdivision of NASA's Goddard center and still closely related to the Langley center. The General Accounting Office and NASA had clashed recently over executive privilege in withholding certain documents relating to the selection of McDonnell as the prime contractor for Mercury. This furnished ammunition for some critics of NASA's industrial relations. But the decentralization policy of NASA was approved by McKinsey, with certain reservations taken in part from STG's experience.[88]

Through the winter and spring of 1960 the managers of Mercury both in Washington and in Virginia were learning to adjust to the limits imposed by a new technology and by the necessity to coordinate diverse, far-flung, and sometimes perverse human organizations of technicians and craftsmen. While they chafed at the slipping schedules, worried over technical details, swatted at gadfly reporters, and tried to anticipate every contingency in their planning for the missions ahead, Gilruth and his associates in management and systems engineering were just as surely learning to take their tumbles as were the astronauts in their centrifuge rides and in other exotic simulators.

McDonnell's capsule No. 1 finally arrived at Wallops Island on April 1, 1960, cleaned up but stripped of most of its subsystems, to be groomed for a test of its escape rocket, parachute recovery, and landing system. Petynia and Dennis F. Hasson had written a thick catalog of expectations, prescribed procedures, schematics, and checkoff lists for this "off-the-pad abort" test. While Alan Kehlet and Herbert G. Patterson worried over alignment and the abort sequence system, Wallops personnel prepared the canted pad and supplied logistical support

to the McDonnell and Task Group engineers for a month of preparation. Shake tests and sled tests were run first to ensure readiness before firing.[89]

Finally on May 9 the carefully weighed and balanced capsule pointed its pylon toward the sea. The ignition switch was closed and the escape rocket jerked the capsule away from the ground on its short flight, lasting one minute and 16 seconds but covering half a mile in an arc 2465 feet high. Recovery by a Marine Corps helicopter took only 17 minutes. The only significant defect noted from this test was a relatively poor separation distance when the tower jettisoned.[90]

The "beach abort" was a successful flight and a sterling qualification test, but it was hardly spectacular to the public. Certainly it was not all that STG had hoped to accomplish this long after the last of the development flights late in January. However, MA–1 was coming along nicely. It should be far more impressive in proving the "booster-capsule combination for exit flight and capsule for entry flight." [91] And spacecraft No. 2 was to be delivered to Huntsville at the end of June for static tests and compatibility adjustments with the first Redstone booster. Should it prove trouble-free, then presumably by the end of summer, if everyone worked hard enough and there were no interfering defense launch commitments, two more qualification flights on each of the big boosters should bring the day of the first manned space flight much closer.

On May 15, 1960, however, an event occurred that rekindled premonitions that the first manned space flight might be made by a Russian. In their only announced space launching during the first half of 1960, the Soviets orbited the first capsule large enough (10,011 pounds) to contain a human passenger. Called merely *Sputnik IV* by the Western press but more accurately named *Korabl Sputnik,* or *Cosmic Ship No. 1,* this vehicle failed four days later when its reaction control or attitude control system shot the ship containing its dummy astronaut the wrong way for recovery.[92] Perhaps, just perhaps, the United States might have better reaction and attitude controls than the Soviet Union.

# IX

## From Development into Qualification: Flight Tests

(JULY–DECEMBER 1960)

IN mid-1960, NASA and its Space Task Group hoped soon to begin launching a major qualification flight test for Project Mercury every six weeks. If all went well, these tests of the operational vehicles should permit a man to ride into space before the end of the year. But if Mercury's developmental experience to date was any guide, troubles could be expected to pyramid and might require more than six months to correct. Since the ultimate goal of Project Mercury was to achieve man-in-orbit rather than merely a sounding-rocket ride by a man into space, the Task Group would be running concurrent flight tests with the Little Joe, the Mercury-Redstone, and the Mercury-Atlas combinations. But attention and impetus were focused on the accomplishment of manned orbital circumnavigation.

NASA Administrator T. Keith Glennan sent a memorandum to his Director of Space Flight Programs, Abe Silverstein, on July 11, 1960, prompting him to make every effort to put forward to November the launch of MR–3, long designated the first manned suborbital flight. If that was not possible, Glennan urged Silverstein to hold fast the schedule for the first manned launching before the end of the year. Silverstein replied that the manned event had just been reset for the week of December 5. By mid-August 1960 the most realistic estimate of the earliest possible man-launching changed the program management plans once again and reset the MR–3 launching for mid-January 1961. As late as October 1960, this optimism prevailed while work on capsule No. 7 for MR–3 proceeded "somewhat better than expected." [1]

Having once called the Army's stillborn Project Adam a "circus stunt" because it proposed little more than shooting a man into space, Hugh L. Dryden, Deputy Administrator of NASA, had himself set a precedent for the criticisms of those influential scientists who came to regard Project Mercury as more of an exhibition than a demonstration. During 1959 few had raised their voices against NASA's plans and STG's development program for a manned satellite. But during this election year of 1960, many citizens scrutinized—and Eisenhower even established a commission to study—all national policies, goals, and ideals. This White

House-sanctioned introspection led to some criticism, not entirely constructive, of the civilian space agency, which all too often was equated with Project Mercury.[2]

Most Americans appeared to approve Mercury as a potentially stupendous adventure, and many Congressmen anxiously hoped that NASA would mobilize the Nation's vaunted technological know-how to put the first man above the atmosphere. Although Dryden, George M. Low, and other NASA officials recently had warned repeatedly that the Russians could and likely would achieve manned space flight first, no one in NASA seemed to wonder whether the Soviets would send men on ballistic suborbital missions before committing a man to orbital flight. Most citizens seemed to confuse their feelings of hurt pride with loss of prestige and were reluctant to accept Eisenhower's difficult rationalization that America should abjure any "space race" with Soviet Russia. But NASA followed Eisenhower's leadership in this matter and reinforced the official attitude by insisting that Mercury was an "R and D" program whose pace could not be forced.[3]

Glennan in his public statements appeared torn between the pressures of public sentiment expressed through Congress and the news media, on one hand, and the demands of loyalty to the Chief Executive and to technological realism, on the other. Aware of the Nation's late start in rocket propulsion development and yet of its amazingly rapid achievement of a workable ICBM, Glennan knew that the United States still did not have the weight-lifting prowess to join an avowed contest with the U.S.S.R. But Glennan also shared the aerospace community's satisfaction on May 20, 1960, when the Atlas first flew higher than 1000 miles and over 9014 miles downrange from Cape Canaveral into the Indian Ocean. By this time the Thor and Jupiter intermediate-range missiles were operationally deployed abroad. The Titan ICBM, in spite of some developmental failures, was emerging into a second-generation intercontinental missile.[4]

Mercury still was only a fractional part of NASA's total space effort, but publicity and public interest had reinforced each other until the manned program clearly had become the most promising hope of "beating" the Russians into space. When the Soviets orbited *Korabl Sputnik II* on August 19 and the next day recovered two dogs, Strelka and Belka, from it, grounds for complacency among Americans evaporated.[5] National phobias, stimulated by partisan criticism of the alleged "missile gap," were further distorted by technological chauvinism with respect to Soviet accomplishments in space. Popular attitudes were exacerbated after the "spirit of Camp David" was destroyed by the U–2 incident and after Khrushchev used the U–2 affair to destroy the summit conference in Paris.

Speculations on high policy and international relations were not the business of the field workers on the Mercury program. But as citizens they could not avoid being aware of some wondrous possibilities for the historic significance of their work. Both landlubbers and space lovers could find many excellent reasons to think that the ICBM and nuclear warheads might possibly become plowshares of peace rather than tools of terror if directed toward the exploration of space.

Peaceful coexistence and even international cooperation might be force-fed by the exorbitant economics of the competition to put men into orbit. Whatever one's particular brand of concern, there were motives aplenty to work on Project Mercury.

Toward the end of June 1960, the Space Task Group took another hard look at the status of Project Mercury. Having formalized three separate series of engineering inspections and tests—progressing from development through qualification into reliability phases—STG faced with increased confidence some criticism from technical associates. It felt it could gauge accurately the soft spots in the major systems for Mercury. Of the 17 nominal systems for the capsule, all but five or six by June were reported finished with qualification tests and almost done with reliability testing. The major unfinished items were the reaction control system, pyrotechnics, the retrograde and posigrade rockets, and the satellite clock.

Capsule system tests had revealed that certain pressure regulators, solenoid and relief valves, and thrust chambers for the reaction controls using corrosive hydrogen peroxide were going to be troublesome when operating in a high vacuum. On the other hand, the environmental system was progressing better than expected, with only five components still unqualified: the emergency oxygen bottle, a pressure reducer assembly, the odor and carbon dioxide absorber, a high-pressure oxygen transducer, and a suit-circuit water separator. The abort sensing and implementation system (ASIS) for the Atlas was 95 percent qualified, but its counterpart for the Redstone was not.[6]

The communications and tracking network faced four outstanding problems: no one had much experience with Atlas guidance and tracking at long ranges and low elevation angles; the reliability of the high-speed data links was unknown; capsule antenna patterns were erratic enough to make radar acquisition problematic; and control procedures and techniques as yet were untried.

Astronaut training, the Task Group believed, was virtually complete for disorientation, tumbling, and familiarization with high levels of carbon dioxide absorption. Adaptation to weightlessness and lectures on space sciences were 90 percent complete, but training in navigation and communications (at reduced pressures and with high heating, noise, and vibration rates) was less than a third finished. The training of ground crews in procedures for preparing, launching, and monitoring an astronaut in flight had only just begun. And NASA's planning for recovery operations in the summer of 1960 was grandiose, asking "virtually for the deployment of the whole Atlantic fleet." This requirement came down abruptly after NASA met with the Navy at the Pentagon and was shown that fleet operations of this scope might cost more than the entire Mercury program.[7]

The climax of the debate over reliability analyses came in early summer 1960, when NASA Headquarters decided to issue an independent contract with McDonnell for making assurance doubly sure. Associate Administrator Richard E. Horner and his deputy, Nicholas E. Golovin, the mathematical systems analyst who had come to NASA from the Advanced Research Projects Agency, achieved

their first point on June 9, 1960, when a separate contract with McDonnell was signed for a reliability study of all Mercury capsule systems. Estimated to cost $52,892 with a fixed fee of $3,323 and planned to be administered by the Bureau of Naval Weapons representatives in St. Louis, this small contract was designed to provide Horner's office with the data it needed to analyze and evaluate the reliability efforts and achievements of McDonnell, of all 10 capsule subcontractors, of some 200 suppliers, and indirectly of STG's reliability monitoring and mission planning.[8]

Golovin's approach to a reliability prediction program was unusual to both the Space Task Group and to many of his professional colleagues. It reversed the common procedure of beginning with parts analysis and proceeding to the whole system. Golovin had recently explained his theoretical point of view before the American Society for Quality Control, citing other missile program precedents for inverting the crucial problem: "start with a definition of failure for the system, and then work back through subsystems and components to the data on parts failures." Glennan and Horner had approved this approach as an aid to fulfilling their desires for better "confidence coefficients" before accepting the readiness of the capsule for unmanned and manned suborbital and three-orbit missions. This kind of systems analysis used deduction and fully exploited "numbers game" techniques and data processing machines to check on the inductive systems engineering of STG and McDonnell. The experimentalists at the working levels, and many of the engineering managers, including STG's Director, Robert R. Gilruth, believed they saw a worthless expenditure of effort in this innovation.[9]

NASA Headquarters saw STG dragging its feet on this issue by the end of June. Glennan therefore tried another tack. He wrote directly to James S. McDonnell, shortly after a personal visit and briefing at the factory:

> As you know, during the last month there have been a number of discussions between my Office of Reliability and Systems Analysis and various members of your staff on the problem of Mercury capsule system reliability. These talks were the result of my having directed the Office of Reliability and Systems Analysis to prepare for me an objective quantitative evaluation of the anticipated mission and flight safety reliability of the Mercury capsule system. It has now been brought to my attention that discussions have not yet resulted in mutual agreement on getting this job seriously underway.
>
> I would appreciate it if you would give the matter your personal attention and have your staff responsively consider providing, as promptly as possible, the information detailed in the enclosed "Proposed Work Statements for McDonnell on Mercury Capsule System Reliability."
>
> If you foresee any serious problems in this connection, I would appreciate your bringing them directly to my attention, and I will be glad to set up a meeting in Washington to reach a full meeting of minds.[10]

The work statements enclosed in this letter, prepared by Golovin's assistants Landis S. Gephart, William Wolman, and Catherine D. Hock, called for precisely defined reliability definitions, assumptions, diagrams, equations, and estimates of each

subsystem design, together with all available test data from every source. The basic reasons for requesting this information were to allow NASA "to review and evaluate the techniques and the data employed by McDonnell" in its reliability report (No. 7007) issued almost a year earlier, and "to update and upgrade the reliability predictions and probability equations" for mission success in the light of uneven changes of component parts supplied to McDonnell:

> With all its subcontractors, McDonnell has established a reliability requirement for each major equipment. This requirement has been expressed either as a mean time between failures for a continuously operating device or as a probability of success for a single shot device, and has been incorporated as a firm contractual requirement in the appropriate McDonnell Specification Control Drawing. McDonnell also recognizes that "a requirement without a test to demonstrate compliance with it is meaningless." Accordingly, McDonnell has specified a variety of tests aimed at demonstration of the reliability requirements imposed on its subcontractors.

Golovin and associates wanted to examine all test plans and test results on every Mercury capsule component from pre-installation acceptance through systems, compatibility, qualification, and life tests. In short, they wanted virtually a whole library of files at McDonnell opened for their inspection promptly, within two weeks if possible. This was not quite possible, but the founder of McDonnell Aircraft did reply personally to Administrator Glennan in mid-July:

> I am happy to inform you that our company started work on 9 June 1960, the same day on which Dr. William Wolman made his first specific request, even though this request was only verbal [sic]. Our company is now at work on every one of the programs therein outlined even though we still have no contractual authorization for any of it.
>
> * * *
>
> We are in full accord with providing as fast as humanly possible (without diluting other Project Mercury effort) whatever work is desired by NASA to assist in the reliability evaluations of Project Mercury. . . .[11]

A few days later Golovin's group, having requested Silverstein to show STG how invidious was its prejudice against the "numbers game," journeyed down to Langley Field and briefed the Task Group on how Headquarters proposed to raise quality by quantitative methods. Reliability goals for each major capsule system, progressive analyses, and periodic reviews, plus a new order of simulated mission-testing stringency, were proposed and accepted by STG. Since the last major reliability meeting at Headquarters on February 29, 1960, had been so acrimonious, STG was surprised to find how little difference there now appeared to be between Golovin's approach to reliability and its own. On July 21, Paul E. Purser logged this note for Gilruth: "Spent most of the day in the meeting with Dr. Golovin, et al. They sounded fairly reasonable. If we had held such a meeting several months ago, there would have been a lot less misunderstanding." [12]

Shortly after this rapprochement, Horner resigned from NASA to go to indus-

try, Golovin resigned later to join the President's Science Advisory Committee staff, and Gephart and Hock obtained an expansion of the McDonnell reliability contract to cover the astronaut's task description and performance evaluation. Glennan meanwhile pressured Silverstein, who pressured Gilruth, to do something formal about taking into account contemporary mathematical techniques used in missile programs to enhance managerial confidence in reliability, hence in readiness before a launch. Gilruth in turn gave the job to John C. French, who proceeded to organize a "reliability and quality assurance office" in the Space Task Group. There was special significance in the word "assurance," because STG had by no means capitulated to the statistical approach nor to the mathematicians' belief in the efficacy of reliability prediction.[13]

Had the qualification flight tests actually started earlier, perhaps much of the debate over what to expect from Mercury launches would have been obviated. But while still standing on the threshold of the major flight test program after almost two years of virtually simultaneous work on detailed design, engineering, and manufacturing, the Mercury spacecraft developers had to talk out some of these difficulties before they could call for a vote. Far more significant than the formal reliability program in the long run were the test philosophy, test programs, and the test work in "space chambers" that could more realistically simulate the hot/cold vacuum of the exospheric environment.[14] To move in that direction required a move toward the "spaceport" at Cape Canaveral, Florida.

## Moving to the Launch Site

The imminent shift from development into the operational phase of Mercury was reflected in several different ways. Military and industrial relations at Cape Canaveral were undergoing rapid change as management and launch facilities were partially modified to accommodate the influx of a new team for manned space flight. Melvin N. Gough, the senior test pilot who had established NASA's basis for operations at the Cape, departed for a job with the Civil Aeronautics Board, and into his shoes stepped G. Merritt Preston for STG and Kurt H. Debus for Marshall's launch operations, now also a part of NASA. The Air Force also added more help for NASA support activities under Colonel Asa B. Gibbs and J. W. Rosenberry. Overcrowded facilities and overlapping checkout and launch schedules were causes for interminable official dickering but not for any program delay. Project Mercury eventually acquired Hangar S and launch complexes 56 for Mercury-Redstone and 14 for Mercury-Atlas.[15]

Although the rank and file of the Space Task Group were barely aware of the new liaison between NASA Headquarters and McDonnell reliability experts, the quest for quality control at the working level was entering a new phase. In the early summer of 1960, about 50 men from STG established residence in Florida. John F. Yardley, along with about 80 McDonnell technicians, set up shop in mobile-home trailers around Hangar S, in the industrial area within the fences

of Cape Canaveral. By the end of the year the number of technicians working on the capsules for preflight checkout at the Cape had grown to more than 400, most of the increase made up by contract personnel.[16]

At the McDonnell factory in St. Louis, peak employment on Mercury systems had reached 880 in April 1960. After that, there was a gradual decline in Mercury production workers as Yardley's field team increased to 120 by summer's end. Because STG had called for the first four capsules from McDonnell's production line before they were entirely finished, the maximum of 427 workers on the factory floor in May 1960 declined with the buildup of preflight polishing activities at the Cape. Yardley and his crews soon became the center of attention for unofficial helpers and kibitzers from other organizations and contractors, many of whom were glad to provide materials and tools that were urgently needed and in short supply among McDonnell people at the Cape.[17]

Yardley, his assistants at the Cape—E. F. Peters and Robert L. Foster—and other working engineers knew little about the separate reliability contract between NASA Headquarters and McDonnell. Walter F. Burke, Logan T. MacMillan, and the quality manager, N. E. Covinsky, did know that this extra business was coming to their company through separate channels, but they and their production engineers were so busy trying to make each capsule work properly that they too could see little sense in the "numbers game." Each system and subsystem seemed to have its own personality. But to guard against overemphasizing these individual idiosyncrasies, capsule No. 10 was set aside as the standard test article at McDonnell. As preflight checkouts at the Cape uncovered more and more unique difficulties, the need for still more stringent quality control was made plain.

No one recognized this more than Yardley, who in the summer of 1960 urged his company to institute a new order of reliability tests. He did not insist on statistical performance data, but he did enjoin improvement of environmental-chamber reliability testing of components. Robert L. Seat, McDonnell's senior test engineer, was pressed by Silverstein in Washington, by Lewis R. Fisher of STG, and by Yardley from the Cape, as well as by the burgeoning number of test requests between McDonnell departments, to prepare specifications for an exhaustive environmental reliability testing program. On September 26, 1960, the project to flight-test a man in orbit was supplemented by an authorization to ground-test the capsule in a simulated mission through physical environments in a "space chamber." This simulated orbital test program gradually became known as "Project Orbit."[18]

The reaction control system on capsule No. 2 was giving Yardley headaches. In general the power and sequential systems on all capsules were full of "glitches," or minute transient voltages from inexplicable origins. Surely more problems could be expected from space operations. So the simulated mission test program, designed specifically to detect unknown anomalies arising from four and a half hours of continuous operation in a vacuum alternately hot and cold, like "day" and "night" for the manned satellite, was welcomed by all hands. Unfortunately

it would take six months to build, install, test, and modify the new space chamber test facility at the McDonnell plant. Several smaller, less sophisticated "man-rating" vacuum chambers had already been used but none was capable of simulating the extremes of orbital conditions.

Prelaunch preparations at the launch site began in June 1960 with an understanding between STG and McDonnell that some rework would be performed there in addition to extravagant preflight checkout tests, but the extent of the last-minute work to be performed and the number of discrepancies to be corrected became so great that "preflight checkout" quickly came to be a misnomer. Under Preston at the Cape, John J. Williams eventually came to head the "Preflight Operations" division, instead of being simply "checkout" crew chief. Paul C. Donnelly, Archibald E. Morse, Jr., A. Martin Eiband, Walter J. Kapryan, and Jacob C. Moser gradually became involved with wholesale systems engineering as the thoroughgoing checkouts in Hangar S expanded.

Gilruth laid down the law "for what is perhaps the most important single requirement in our programs: that designs, procedures, and schedules must have the flexibility to absorb a steady stream of change generated by a continually increasing understanding of space problems." This policy of correcting every discovered deficiency and of modifying each spacecraft down to the finish line at launch time was what Gilruth meant by an "R and D" program; it sacrificed cost and schedules if necessary in the interest of quality or reliability as the experimentalists understood it.[19]

Through August 1960 "space chamber" ground testing for Mercury had consisted primarily of the capsule systems tests for integration and compatibility in a relatively mild vacuum and of the manned environmental control system tests simulating an altitude of 40,000 feet. McDonnell had detected many design deficiencies in these test programs. Now early development failures, arising from unanticipated interactions between parts and components and from errors in estimating the effects of environmental extremes, became most troublesome.

At St. Louis in mid-August, the "Development Engineering Inspection," a milestone meeting comparable to the Mockup Review, brought together for three days all the chief actors and participants in the hardware work on the capsule. Walter C. Williams and Kenneth S. Kleinknecht were eager to institute this old Air Force custom—the "D.E.I.," as they called it—as a basic check on systems integration and configuration control. When on August 18 the 30 members of the NASA inspection team departed, they were well assured that the Mercury capsule on display (No. 7) was safe for manned flight, but only for a suborbital mission. Orbital flight would require a higher order of precautions for reliability. "Project Orbit," taking advantage of recent advances in vacuum technology, promised to pioneer this new dimension in development engineering by bringing the space climate down to Earth. Capsule No. 10 was specifically set aside in September for environmental chamber testing at McDonnell for orbital conditions.[20]

## FLIGHT TESTS

While the Tenney Engineering Company of Union, New Jersey, was building the new vacuum chamber for man-rated environmental testing of the capsule at the Cape, and while McDonnell engineers were moving in to augment STG's preflight checkout group there, one NASA operations expert transferred back to tidewater Virginia to help Gilruth and French formulate policy and establish STG's competence to judge reliability and flight safety issues. F. John Bailey, Jr., was Gilruth's choice for the man most likely to reconcile the differences between reliability based on experience and on expertise. Bailey believed an engineer needed 15 or 20 years' experience in any specialty to be a proper judge of the state of his art; he also appreciated the value of mathematical models in the redesign stages of technological evolution. But he quickly became convinced, particularly by studying the carefully balanced engineering compromises between efforts to make the boosters perfect and to perfect the escape system, that Mercury dependability could hardly be improved except by flight testing.[21]

Everyone recognized dangers in the pragmatic experimental approach to pilotless spacecraft research, but each calculated the risks differently. Silverstein and the new Associate Administrator, Robert C. Seamans, Jr., who succeeded Horner at this post on September 1, 1960, were among those at Headquarters who justly feared that overemphasis on the uniqueness of each production capsule and on STG's policy of continuous rework might lead to so many "quick fixes" that a pyramid of unobtrusive changes could cover up the truth about whatever might go wrong.[22]

Perhaps the most pertinent of these difficulties with systems integration derived from NASA bench tests of the reaction control system. The manufacturer of the RCS, Bell Aerosystems Company, ran its qualification test program from August through October 1960 and reported all phases of the testing satisfactorily completed. Subsequent tests by McDonnell, STG, other NASA engineers, the preflight teams at the Cape, and eventually by the workers on Project Orbit revealed innumerable electrochemical and electromechanical problems in simulated environments that required small changes here and there and eventually everywhere. The thrust chambers, metering orifices, solenoid valves, expulsion bladder, and relief valves each presented developmental flaws that were "solved" more often by improvisations than by scientific redesign. Karl F. Greil, a thermodynamicist who was working for Grand Central Rocket Company in 1960 to perfect the escape pyrotechnology for Mercury, joined STG and its reaction controls test team in 1961 and tried in vain to apply the same perfectionistic standards to this vastly more complicated and inherently less reliable system of moving parts:

> This is the irony: the results that counted in Mercury's RCS were due to changes of the screen, heat barrier, and orifices, all of which were made upon simple first thought. On the other hand, the large amount of experimentation on the valve resulted merely in the assurance that nothing needed to be changed so far as valve design was concerned. This irony, that the simple approach

> did the entire job while the sophisticated approach merely resulted in an "Amen", is indeed worthy of reflection, because it has in store both a risk and a lesson: a lesson because there is so much glamor cast on sophisticated pretense and so much disregard for the profane causes of all kinds of trouble; a risk because the simple remedy which did the job once without ever having become clear just how it really worked, such success without perspiration is likely to remain confined to its own historical case. But having established a precedent, it is bound to seduce us into relying on it, if it is not even bound to become a myth and a dogma.[23]

Fortunately neither the reaction system nor the environmental control system for the Mercury suborbital flight had to be so nearly perfected as the escape, structural, and landing systems. The development engineering inspection confirmed the faith of most project engineers, in spite of a spate of impatient criticism from outsiders, that capsule sequencing, electrical, communications, stabilization, environment, pyrotechnical, instrumentation, and landing and recovery systems were virtually ready to fly. McDonnell issued a revised set of detail specifications for capsule No. 7 soon afterward. The Aerospace Corporation, spawned from and now replacing Space Technology Laboratories (STL) for Air Force systems engineering activities, published in September its basic planning document, the "General Flight Plan: Atlas Boosters for Project Mercury." [24]

If Project Mercury were on the verge of technological bankruptcy, as some critics claimed, the problem was that man was still land-locked by inadequate boosters. The Redstone for Mercury was still not man-rated. The first Mercury-Atlas flight on July 29, 1960, not only did not qualify anything, it seemed actually to have disqualified an indispensable part of Mercury. It cast everything into doubt.

### Atlas-Mercury One: A Complete Failure

Late in February 1960 the Air Force Ballistic Missile Division (BMD) and Space Technology Laboratories (STL) had been hosts for a meeting in Los Angeles of people from Convair/Astronautics, McDonnell, and the Task Group who were to determine the final details of the ultimate booster-capsule system for Project Mercury. Already STG had decided unilaterally, as was its prerogative, to make the next shot split the difference between the Big Joe development mission and a full qualification flight test of the Mercury-Atlas configuration on a simulated reentry from orbit. To the Task Group, this configuration and mission had long since been known as "MA–1," but Air Force and Convair engineers usually transposed the names and spoke of "Atlas-Mercury" No. 1. As in many other particulars, which things should be first still was debatable. Maxime A. Faget recorded his impression of the central technical debate at the Mercury-Atlas meeting on February 26:

> STL/CVA representatives made an impassioned plea to use the escape tower on the MA–1 shot. Only with the escape tower on, can the Atlas people

determine the structural bending modes on the Atlas and, consequently, the adequacy of their control system to accommodate them. The writer explained that the tower was deleted from this flight only after a great deal of deliberation at the Space Task Group, that much water has gone over the dam since then, and to change now would be very difficult. Although I agreed to take back to the Space Task Group management their desires for further consideration, they were informed that there was virtually no chance that the change would be made.[25]

As the MA–1 launch date approached, the Langley outfitters of the Big Joe capsule installed inside the shell of McDonnell's capsule No. 4 another instrumentation package, built by Lewis Research Center and STG electronics technicians. Shipped to the Cape in mid-May, loaded with 200 pounds of sensing instruments—including two cameras, two tape recorders, and a 16-channel telemetry system—the MA–1 payload was equipped to measure some 50 temperatures (mostly on the afterbody); pitch, yaw, and roll rates; positive and negative accelerations; cabin and external pressures; and noise and vibration extremes. Besides the missing 1060-pound escape system, this payload also lacked the environmental control system, the astronaut couch and control panel, and the attitude-control and stabilization-control jets. An inert paste replaced the solid fuel in the retrorockets. For several months before the Atlas 50–D booster arrived at the Cape, Joseph M. Bobik, of the STG Launch Operations Branch, had work abundant as the inspector of the MA–1 capsule. Meanwhile Sigurd A. Sjoberg, John D. Hodge, Richard G. Arbic, John P. Mayer, and Robert E. McKann were hastily revising the mission directive, data acquisition plan, and general information on recovery requirements, landing area predictions, and a summary of calculated preflight trajectory data.[26] Robert F. Thompson, Christopher C. Kraft, Jr., and Charles W. Mathews listed in order of importance the test objectives of the MA–1 flight:

1. Recover the capsule.
2. Determine the structural integrity of the Mercury capsule structure and afterbody shingles under the maximum heating conditions which could be encountered from an orbital launching.
3. Determine Mercury capsule afterbody heating rates during reentry (for this purpose 51 thermocouples were installed).
4. Determine the flight dynamic characteristics of the Mercury capsule during reentry.
5. Determine the adequacy of the Mercury capsule recovery systems.
6. Familiarize Project Mercury operating personnel with launch and recovery operations.[27]

When capsule No. 4 actually arrived at Cape Canaveral on May 23, it was as complete as it was supposed to be except for flight instrumentation, parachutes, and pyrotechnic devices. Following a satisfactory test of the leakage rate of its

pressure shell, the capsule's miles of wiring were verified while the instrumentation system was subjected to final bench tests. Minor difficulties with instruments and in using a new weight-and-balance fixture added two weeks to the work period. For integrated systems tests to verify the sequencing and monitoring during the reentry, the capsule was moved into the newly constructed clean room in Hangar S.

When every minor discrepancy had been corrected and the calibration curves for various units had been established, the spacecraft was moved out to launch complex 14 for the first mechanical mating of a Mercury capsule with an Atlas booster. The alignment was good; no rework was required for the umbilicals or for the complex wiring in blockhouse consoles. But mechanical problems with Freon lines and with some electrical contacts in the mating ring caused a delay. Taken back to Hangar S for dismantling to rework certain instrumentation and telemetry packages, the capsule again was transported to the pad and mated to the launch vehicle in preparation for the flight acceptance composite test, known by its acronym, FACT. From July 13 to 18 engineers stood on the bascule of the gantry, working to conclude the FACT satisfactorily.

Meanwhile the Atlas crews were checking out their vehicle. Friendly rivalry between the propulsion and payload people produced many wagers over which system would cause the next postponement, and whether the capsule or the booster would be first to report "all systems go." On July 21, the flight readiness firing, which was a dress-rehearsal static-firing test, tested the three Atlas engines and measured the vibrations and acceleration strains suffered by the capsule. Atlas partisans won a bet at this point; atop this particular capsule the short metal legs of the "stub tower" created some unique antenna and telemetry difficulties with power amplifiers, commutators, and a high voltage standing wave ratio. The purpose of the "stub tower" was to support a thermal fairing over the antenna and parachute canister. Again the spacecraft was returned to the hangar. The tape recorders and cameras were removed, reloaded, and reinstalled. The telemetry was checked. The recovery section equipment was removed, then reassembled with live pyrotechnics. The capsule again was balanced, weighed, and aligned optically before its final union with the booster.[28]

McDonnell's virgin spacecraft No. 4 moved to the seaside launch pad dressed in a polyethylene raincoat on July 24. This time it nestled nicely on top the Atlas, and the umbilical insertion and pull tests shortly certified readiness to begin the countdown. Wet weather made it difficult to keep the pyrotechnic connections dry, but otherwise preflight checkouts were completed on July 26, 1960. For the benefit of Administrator Glennan, George Low summarized the expectations for Mercury-Atlas 1: [29]

> The primary objective of this test is to determine the integrity of the Mercury capsule structure and afterbody shingles when subjected to the maximum heating conditions which could be encountered in any Mercury mission.
>
> Maximum velocity: 19,000 feet per second
>
> Maximum altitude: 98 nautical miles

Range: 1300 nautical miles
Peak deceleration: 16.3 g
Time of flight: 16 minutes

Heavy rain pelted the Cape early on Friday morning, July 29, 1960, but the cloud ceiling rose high enough to be considered acceptable for a launching. During the final 35 minutes of countdown before launch time (T), 48 minutes were accumulated by delays or "holds" because of bad weather; liquid oxygen tank-topping delays; and telemetry receiver difficulties. In the blockhouse Gilruth and Walter Burke watched Walter Williams direct operations and Aleck C. Bond, the project engineer, sweat away the minutes, while across the Cape at Central Control, other Air Force, Navy, and Convair officers and officials also watched and waited. Before their consoles in the blockhouse sat the Convair test conductors Kurt Johnston and William Williams; Scott H. Simpkinson, the payload test conductor; Harold G. Johnston, the ground instrumentation coordinator; Jacob Moser, the instrumentation engineer; B. Porter Brown, the launch coordinator; Richard Arbic, the range coordinator; and Donald C. Cheatham, the recovery coordinator. At 7:25 the weather looked cooperative in the impact area, where recovery aircraft and ships were reporting a visibility of five miles and a sea state of mild swells. So the gantry was ordered to back away, leaving MA–1 poised alone in the rain, ready for the final count. Intermittent holds for minor status checks left only 7 minutes of count at 9 o'clock.

Finally at 9:13 the man-made thunder clapped as the Rocketdyne engines spewed forth their reaction energy. The noise grew louder for several seconds as the Atlas pushed itself up on its fiery blast by inches, feet, and yards. Out of sight in seconds as it pierced the cloud cover, Atlas 50–D could still be heard roaring off in the distance. The initial phases of the launching appeared to be normal. Then everything went wrong:

> About one minute after liftoff all contact with the Atlas was lost. This included telemetry and all beacons and transponders. About one second before telemetry was lost, the pressure difference between the lox and fuel tanks suddenly went to zero. It is not known whether this caused the failure or was an effect of the failure. There was no progression of unusual events leading up to this pressure loss. During the remaining second of telemetry, the Atlas flight path appeared to be steady.

By telephone and teletype data links, Low in Washington pieced together the bad news on MA–1 and continued to dictate an immediate preliminary report for the administrator and his staff:

> As you know, the abort sensing system was flown open loop in this test. This system gave two signals to abort, apparently about the same time as the tank pressure differential was lost. These signals were monitoring missile electrical power and thrust; although the tank pressure differential was also monitored, no abort signal was received from this source. In the MA–1 mission, all of these signals were merely monitored, and were not connected to any of the capsule systems.

> The current speculation is that the Atlas either exploded, or suffered a catastrophic structural failure. Some observers reported that they heard an explosion, but this is not verified. The failure occurred at the time of maximum dynamic pressure, at an altitude of about 32,000 feet, and a velocity of about 1400 feet per second.
>
> The capsule separation systems were not to be armed until about three minutes after launch, and therefore the capsule remained attached to the Atlas or to pieces of the Atlas, until impact. Capsule telemetry continued to impact and indicated violent motions after the Atlas telemetry ceased. Temperatures and shingle vibrations flutter were recorded. Since all shingle thermocouples gave readings to splash, it is inferred that none of the shingles tore off. Impact occurred about seven miles off shore in an area where the water depth is roughly 40 feet. At the time of this writing, ships were still searching for debris.[30]

It was a sad day for Mercury. It was especially frustrating for those nearest to the Atlas-Mercury phase, for they knew only that MA–1, either Atlas 50–D or capsule No. 4, or both, exploded on its way through max q. They did not know precisely what had happened because the weather had been so bad as to prevent visual and photographic coverage. In Washington, at Langley, at the Cape, and in southern California, postmortems were held for two weeks, until a conference on August 11 marshalled the parties most interested in the MA–1 malfunction, along with all the flight records, telemetry, and tape recorder data. Salvage operations had been able to recover only small portions of the capsule, the adapter-ring, and the booster. Presiding at this meeting was Major General Leighton I. Davis, the new commander of the Air Force Missile Test Center, who had relieved Major General Donald N. Yates in June as the Department of Defense single-point-of-contact for support of Project Mercury. On August 22, Warren J. North summarized the "quick-look" opinions of NASA and STL but not of Convair/Astronautics:

> Both the NASA and STG localized the difficulty within the interface area between the capsule and the booster. A metallurgist from STL explained that it appeared the plumbing to the Atlas lox boiloff valve had failed due to fatigue. One would not ordinarily suspect a fatigue failure after such a short period of time, however, the NASA analysis showed that the lox valve plumbing could have failed if a 30 g oscillation existed at approximately 300 cycles per second. Culbertson (Convair) admitted that the lox valve was poorly supported and that 30 g was a feasible magnitude of acceleration. Vibration measurements show a two and one-half g vibration of the booster airframe, consequently a 12 g amplification factor would have been required at the lox valve.
>
> Jim Chamberlin, STG, has been appointed chairman of a joint committee to resolve the MA–1 incident and provide a fix prior to MA–2. Initial reaction of this committee would cause the establishment of a hardware mockup at McDonnell which would include the pressurized lox tank dome, lox valve, adapter, and capsule. This mockup will be vibrated in order to isolate resonance or amplification factors.[31]

## MA–1
## July 29, 1960

*MA–1, a suborbital flight designed to check capsule structural integrity under maximum heating conditions, rose into the low rain clouds above Cape Canaveral (right) and mysteriously exploded one minute after lift-off. Pieces were meticulously collected (below) and painstakingly reassembled (below right). The engineering study delayed Mercury about 6 months but led to vastly improved interface between spacecraft and booster.*







Two weeks later in San Diego, another committee of nine metallurgical engineers, a majority of whom were not from Convair, examined microscopically the hypothesis that MA–1 was destroyed by metal fatigue of the lox-vent valve elbow. "All conferees agreed finally that the factor at hand was not the primary one." [32] The official flight test report issued two months later concluded with these remarks:

> The Mercury Atlas No. 1 flight test was abruptly terminated approximately 58.5 seconds after launch by an in-flight failure of an undetermined nature. Solid cloud cover at the time of launch precluded the use of optical records in the investigation of this failure. The following conclusions are drawn regarding this flight test:
>
> a. None of the primary capsule test objectives were met.
> b. The structural integrity of the capsule was maintained throughout the flight until impact with the water. A substantial part of the adapter remained attached to the capsule to impact.
> c. The capsule onboard instrumentation performed in a highly satisfactory manner throughout the flight.
> d. The onboard instrumentation showed the presence of shingle vibration of a non-destructive nature.
> e. All Department of Defense support for the operation was very good.[33]

In mid-September one of the most important of the regular monthly meetings of the Mercury-Atlas coordination panel took place in the administration building at Patrick Air Force Base, Florida. Lieutenant Colonel Robert H. Brundin, Major Charles L. Gandy, and Captain I. B. Hanson were the BMD representatives, while Philip E. Culbertson and C. J. Holden represented Convair. Bernard A. Hohmann and Ernst R. Letsch were representing Aerospace Corporation, since STL was phasing out of Mercury. John Yardley, R. L. Foster, and J. T. Heard were present for McDonnell.

First and last on the agenda of this meeting were questions concerning better ways of inspecting and solving problems at the interface between the capsule and the booster. Charles Mathews, the chairman, began the meeting by insisting that in spite of the MA–1 failure, the overall Mercury-Atlas schedule could still be maintained. Hohmann suggested that a new seven-man joint capsule-booster interface inspection committee be established. This was done, and members representing all contributing organizations were named. Regarding the unsettled question of MA–1, Mathews briefly described several fruitless fact-finding activities and the need for additional instrumentation to determine the cause of failures like MA–1. No new hypothesis had yet emerged from the several test programs, so the 23 members of this coordination panel reexamined each other's previous answers to the enigma of MA–1. The 11 members from STG vetoed a proposal by the Air Force Ballistic Missile Division to establish still another "Mercury-Atlas interface panel." [34]

Although the MA–1 investigation was unsatisfying, the launch operations committee reported that MA–2 was so nearly ready for a November launching that

there was little time for looking backward and no time for regret. Then on September 26, 1960, a lunar probe attempt by NASA, using Atlas-Able 5–A, also failed severely. This forced a wholesale review of the Atlas as a launch vehicle. Everybody responsible for MA–1 was trying to determine the cause of that failure, but each only discovered that there were too many other bodies, both organic and organizational, partly responsible.

Late in October, before the national elections and before another Mercury flight test had come to pass, Gilruth and Williams held another periodic press conference for the benefit of curious reporters. Inevitably the question was asked, "Are you satisfied that you have pinpointed the reason for the MA–1 failure?" "No," Gilruth answered. "We successfully salvaged the capsule and can account for all parts." His interrogator continued, "Do you believe that parts in the Atlas' upper stage caused the failure?" Gilruth replied, "We have explored this. We have answered all of the questions we have asked ourselves—but have we asked the right questions? We can't be sure. That is one of the reasons we are repeating the test. And on MA–2 the interface area will be heavily instrumented." [35]

When MA–2 finally became ready for launch, toward the end of February 1961, the managers of Mercury knew that a repetition of a total failure like MA–1 could easily cause abandonment of the project. The entire promise of the American manned space flight program seemed to hang in the balance. The technical aftermath of MA–1, during the politically sensitive period of the Presidential election and the lame-duck session of Congress, made interrelated technical and political considerations more acute than ever. To distinguish between the two soon became virtually impossible.

## Election Year Appraisals

The day that Mercury-Atlas 1 failed so badly, NASA Headquarters announced plans to follow Project Mercury with a manned space flight program called "Apollo"—a project conceived to carry three men either in sustained orbital flight or on circumlunar flight. Several days later, the X–15 set two new world records when NASA pilot Joseph A. Walker flew the manned rocket on partial power to a speed of 2196 miles per hour and when Major Robert M. White shot it up to a height of 136,000 feet over Nevada and California.[36]

In mid-August 1960, the Air Force accomplished two significant "firsts" within eight days when it managed to recover instrumented packages from the thirteenth and fourteenth attempts in its Thor-Agena-launched Discoverer series of satellites. *Discoverer XIII* dropped its 85-pound capsule into the Pacific off Hawaii on August 11 after 16 orbits; although a mid-air retrieval had failed, frogmen and helicopters from a naval vessel found and returned this, the first man-made object recovered intact from an orbital journey. On August 19, 1960, an Air Force C–119 cargo plane trailing a huge trapeze-like trawl succeeded in being at exactly

the right place at the right time to snare in mid-air the descending instruments from *Discoverer XIV*. That same day, however, the Soviets launched an ark, including the "muttniks" Strelka and Belka, and the next day they recovered the dogs and their live companions (rats, mice, flies, plants, fungi, and seeds) after 18 orbits above Earth's atmosphere. This marked the first successful recovery of living biological specimens from an orbital voyage. Three months later, on November 14, 1960, another C–119 aircraft succeeded in snatching the reentry capsule from *Discoverer XVII*, which carried human tissue, bacteria, spores, and film emulsions to an orbital apogee of 616 miles. For the moment, though, the Soviet achievement was overwhelming in its portents for manned space flight.[37]

On August 12, 1960, after an attempt that had failed in May, NASA's Project Echo succeeded in placing into orbit the first passive communications satellite, a 100-foot-diameter aluminized Mylar plastic balloon, which reflected radio signals beyond Earth's curvature. Launched by a Thor-Delta vehicle into an orbit roughly 1000 miles from Earth and inclined 47 degrees to the equator, *Echo I* was the first artificial moon that could be seen easily with the naked eye by all mankind. Although stargazing aborigines in neolithic cultures of New Guinea and Mozambique probably could see the Echo balloon with the unaided eye better than sophisticates in the smog and haze of urban-industrial centers from California to Kazakhstan, the new pinpoint of light in the heavens was a visible manifestation of the "space age." President Eisenhower's broadcast message reflected from this sphere circling Earth at 15,000 miles per hour proclaimed:

> It is a great personal satisfaction to participate in this first experiment in communications involving the use of a satellite balloon known as Echo. This is one more significant step in the United States program of space research and exploration. The program is being carried forward vigorously by the United States for peaceful purposes for the benefit of all mankind.
>
> The satellite balloon which has reflected these words may be used freely by any nation for similar experiments in its own interests. Information necessary to prepare for such participation was widely distributed some weeks ago.
>
> The United States will continue to make freely available to the world the scientific information acquired from this and other experiments in its program of space exploration.[38]

While the President was pointing to these and other achievements of the United States in the exploration and use of outer space, the Nation was in the midst of a highly contested presidential campaign and congressional elections. Four years earlier it had seemed sheer whimsy, but now the practical values of space exploration and policy decisions on space, missiles, and the Nation were being not only examined but reexamined. In September, a month after Strelka and Belka were orbited and recovered by the Soviet Union, Premier Khrushchev again came to the United States for some personal diplomacy and figurative sabotage in the United Nations General Assembly. Afterward he told reporters that his people were ready to launch a man into space but had not yet made any

such attempt.[39] No longer could Khrushchev's brogan braggadocio be ignored.

Meeting at Barcelona, on October 7, 1960, the Fédération Aéronautique Internationale adopted the first set of rules to govern the award of official records for manned space flight. To be recognized under the "Code Sportif" that had been setting the rules for aeronautical records since 1905, the first flight into space must top at least 100 kilometers; later attempts to set records must exceed the existing record by at least 10 percent. Four categories of performance were set forth: duration of flight, altitude without orbiting Earth, altitude in orbit, and mass lifted above 100 kilometers. To be valid, all claims for records "must be supported by information on the date, time, place of takeoff and landing, identity of the vehicle commander, and any special apparatus used to assist liftoff, landing, or control." [40]

When in mid-October Soviet tracking ships deployed to stations in the Pacific, an alert went out to American forces to expect imminent Soviet attempts to fulfill Khrushchev's boast. In mid-August there had been much talk in the American press that the United States had "rejoined" the space race as a result of recent accomplishments. An Associated Press dispatch on August 8 reported that Abe Silverstein was not particularly dismayed by the MA–1 fiasco and believed that Project Mercury was "essentially along the same time schedule as was initially planned." Congressman Overton Brooks, Democrat from Louisiana and chairman of the House Committee on Science and Astronautics, waxed much more critical of the speed with which Project Mercury was moving. In September Glennan warned Americans to be prepared for new Soviet announcements of space spectaculars. The Mercury astronauts repeatedly were reported confident that one of them could ride a ballistic trajectory either in December or January.[41] In short, the dramatic race to be first to put a man in space made such colorful copy that news editors generally ran stories on the space contest second only to news about the political contest.

The news media both reflected and fostered a widespread restlessness over the apparent failure of American know-how to equal and surpass Soviet rocket technology. Back in October 1959, two years after *Sputnik I*, *Newsweek* had featured an article, "How to Lose the Space Race," itemizing blanket criticisms of all American space programs. To ensure that you have the losing ticket, advised *Newsweek,* simply "start late, downgrade Russian feats, fragment authority, pinch pennies, think small, shirk decisions." [42] At the beginning of 1960, Hanson W. Baldwin, the influential military affairs correspondent for the *New York Times,* had chided the Eisenhower administration for neglecting the power of intangible ideas and had advised the government to seek more advice from political rather than physical scientists: "It is not good enough to say that we have counted more free electrons in the ionosphere than the Russians have . . . we must achieve the obvious and the spectacular, as well as the erudite and the obscure." And in July 1960 one of the deans of space fiction and fact, Arthur C. Clarke, published a

playful, widely viewed article that suggested that the United States had "already suffered a failure of nerve" and forfeited its future by failing to "rocket to the renaissance." [43]

Project Mercury specifically, as 1960 wore on without much to show for the taxpayers' millions, began to be criticized more minutely. Perhaps the most painful sting felt by the Mercury team came from adverse publicity in *Missiles and Rockets,* a weekly defense industry trade journal, on August 15, 1960. There, under the heading "Is Mercury Program Headed for Disaster?" writer James Barr excoriated Project Mercury:

> NASA's Mercury manned-satellite program appears to be plummeting the United States toward a new humiliating disaster in the East-West space race.
>
> This is the stark conclusion that looms in the minds of a growing number of eminent rocket scientists and engineers as the Mercury program continues to slip backward.
>
> These experts, many of whom are already calling Mercury a latter day Vanguard, contend:
>
> The program today is more than one year behind its original schedule and is expected to slip to two. Therefore, it no longer offers any realistic hope of beating Russia in launching the first man into orbit around the earth—much less serve as an early stepping stone for reaching the moon.
>
> Despite precautions and improvements, Mercury continues to be a technically marginal program that could easily end in flaming tragedy. Mercury, at best, is a technical stop-gap justifiable only as an expedient. It is no substitute for what is needed sooner or later, a maneuverable spacecraft similar to the Air Force's much hampered Dyna-Soar.
>
> Mercury originally had the supposed advantage of being cheap, an attribute that made it particularly attractive to the Administration. However, Mercury has proven to be a trip down a dead-end road that U.S. taxpayers are finding themselves paving in gold. Appropriations have reached a quarter-billion to date. They may double.[44]

Although Barr's animadversion could have been discounted in an election year as a plug for more encouragement and funding to the Air Force's Dyna-Soar program, the occasions for self-doubt inside Project Mercury indisputably were becoming more numerous. On September 16, 1960, Gilruth issued a memorandum for his staff that showed the effects of barbs like those from Barr on the morale of the Task Group. The subject of the memo was "Favorable Press Comments (for a change)":

> As most of you know, there have been some adverse comments in the press and trade publications about the progress, or lack of progress, being made in Project Mercury during recent weeks. A number of members of the Space Task Group have expressed concern about these articles.
>
> In any program as broad and complex and as important to our national stature as Project Mercury, it is inevitable that there will be people around us who either will not agree with us, period, or who tend to disagree in one element or another just to be disagreeable. At the same time, there are a number of people around our country who do understand how much work and how much blood and sweat go into an undertaking of this kind.

* * *

> I am personally confident that the work that all of you are doing will bear fruit in the near future. In the interim, I urge all of you to put on your thickest hide, to continue your concerted efforts to make Project Mercury the kind of program it was designed to be, and to reflect with me upon our past accomplishments.[45]

At NASA Headquarters there was serious concern over how to answer public criticisms. On August 14 Warren North sent the Administrator some arguments filling in the contextual background of Mercury schedules:

> Since the negotiation of the capsule contract, McDonnell personnel have averaged 14% overtime for an equivalent 56 hour week. McDonnell has assigned approximately 13,000 people in direct support of Project Mercury. In October 1959, production went on a 7-day week, three shifts per day. Since January 1960 capsule checkout personnel have worked three shifts per day seven days per week. McDonnell is also working three shifts at Cape Canaveral. During the past eighteen months, Space Task Group personnel have been using less than half their annual leave. Many have used essentially no annual leave since February 1959. Space Task Group personnel at Cape Canaveral worked approximately 50 hours a week preparing for flight operations. When the MA–1 capsule was delivered to the Cape on May 23, 1960, this group went on a 60-hour week. During the final month of MA–1 preparations, the launch operations crew was working a seventy-hour week. The forthcoming simultaneous operations with Atlas and Redstone will require a continuation of this type of effort.[46]

On September 9, 1960, George Low addressed a United Press International editors conference at a hotel in Washington on the subject of the progress made in Project Mercury to date. Low began by arguing against three common misconceptions about the project in the public press: Mercury was not, he said, "merely a stunt," not "designed only to win an important first in the space program," and should not "be terminated if the Soviets achieve manned orbital flight before we do." Firmly convinced that the Soviets now had the capability of achieving manned orbital flight, Low tried to persuade the opinion molders of the "fourth estate" to accept Mercury as an indispensable step toward Project Apollo, one which "must be carried out regardless of Russian achievement." This theme subsequently became official NASA policy. The urgency of Project Mercury was transferred onto the higher level of the urgency of manned space flight in general and for the future. "It has been a major engineering task," said Low, "to design a capsule that is small enough to do the mission, light enough to do the mission, and yet has reliable subsystems to accomplish the mission safely." [47]

Within the aerospace community of industrialists, technicians, and Government scientists and engineers, the context described by North and Low needed little explication. Experience with federally sponsored "R and D" programs since 1940 helped them understand the difference between a project rating the "DX," or highest industrial procurement priority, and one designated an all-out "crash" program. Mercury was never a "crash" project in the sense that the Atlas ICBM

or the Manhattan Project had been, in which duplicative and parallel solutions were developed for its most difficult systems. The DX priority for materials, NASA's own first rating, and STG's high "sense of urgency" were tempered always by the rule of noninterference with priority defense programs. In mid-September NASA and the Defense Department agreed to aid each other to avoid duplication and waste by means of a new Aeronautics and Astronautics Coordinating Board, with Dryden and Herbert F. York as co-chairmen.[48]

But the citizenry, through the press, saw these problems in simpler terms. "Project Mercury: Race or Pure Science?" was a banner headline in a Norfolk newspaper of September 11. Richard M. Mansfield related therein how the United States "space fever" had fluctuated over the previous three years:

> Gilruth gets a little angry when people talk about Mercury lagging behind schedule. Some say it is behind as much as a year. Gilruth says this is pure nonsense, that no one can properly put a specific target date on a research program that explores "new frontiers," and is beset by such "detailed problems."
>
> * * *
>
> Gilruth gave assurance that extra money would not have cut time appreciably. He does not believe that a blank-check crash program would save much time even now.
>
> "I think we've done our optimum," he said. "It's just like having a baby. Maybe (with more money) we could have had a lot more of them, but you wouldn't have cut the time on any one of them." [49]

Reporter Mansfield went on to summarize the conflicting attitudes of scientists who "are never in a hurry," with Government employees, including scientists, who must respond to the demand of the electorate to "overtake the Soviets." The eagerness of the seven American astronauts to make their suborbital flights was tempered, he reported, by their recognition that the orbital venture into space had already slipped too far. "There is little doubt among them that the Russians will have been there first," said Mansfield.

Late in September members of the military and industrial community engaged in aerospace and defense business watched with interest for indications where best to invest their votes. The editors of *Missiles and Rockets* addressed an open letter to both the Republican and the Democratic candidates for the Presidency, inviting comments on a "modest proposal for survival." The journal sought specific commitments on the recognition as national policy of the strategic space race with Russia and on the endorsement of a bold long-range program for space projects during the next decade. Candidate John F. Kennedy responded immediately with his concurrence that "we are in a strategic space race with the Russians, and we have been losing. . . . if a man orbits earth this year his name will be Ivan." To this audience Kennedy also explained one meaning of his campaign slogans on "moving ahead" into the "new frontier": "This is the new age of exploration; space is our great new frontier." Vice-President Richard M. Nixon, seeing the issues of an alleged "missile gap" and of national prestige loom ever larger in the

later stages of the campaign, at last replied by vigorously defending the record of the Eisenhower administration.[50] The issue of manned space flight was never clearly joined, here or in the television debates preceding the election. But after the first Tuesday in November, even though the popular vote barely showed a preference, it was clear that the next Chief Executive as well as the Congress would be Democratic and that this meant change.

Project Mercury, as one large and unproven part of NASA, could expect to be influenced by "the gathering storm over space" and some sharp changes in the Nation's defense and space programs.[51] The most forthright change to be expected with the new administration likely would be an honest and open admission of the competitive aspects of space technology. International negotiations on disarmament had failed to produce any further arms control measures since the 1958 Russian-American agreement to suspend atmospheric nuclear testing. Efforts in the United Nations to exempt space as an arena for international rivalries, following the example of the 1959 Antarctica treaty, had so far failed. It seemed purely sentimental to act as if coexistence would become any less competitive. Besides, recent successes of American missiles reinforced the United States' foreign policy of steadfast resistance to Communist encroachments. An Atlas ICBM had again flown 9000 miles for a bullseye in the Indian Ocean on September 19, 1960; the Thor was operational, and the Polaris and Titan weapon systems were in active test phases. A "booster gap" there admittedly was, but the "missile gap" appeared closed, at least to discussion, after the election. The new President would probably find it politic to move speedily but cautiously toward a more intensive national (in contrast to a scientific-international) space program. Kennedy was historically minded and could be trusted to see "the present in perspective," but whether he would consider, as one professional historian did, "manned space flight as the main object of Russo-American rivalry" was entirely moot.[52]

Congressional attitudes before and after the election of 1960 seemed to change less drastically because Congress was already Democratic and had been critical of the Republican "no-race" thesis for three years now. Some of those legislative representatives who felt a need to justify their loyal opposition to Eisenhower and their support for manned space exploration could do so by mailing their constituents a congressional staff report entitled "The Practical Values of Space Exploration." Philip B. Yeager, a staff member of the House Committee on Science and Astronautics, wrote this pamphlet "to explain to the taxpayer just why so many of his dollars are going into the American effort to explore space, and to indicate what he can expect in return which is of value to him." Two editions of this report, before and after the election, began with a quotation from a Russian workman who reportedly complained in a letter published on the front page of *Pravda* for June 12, 1960:

> What do Sputniks give to a person like me? . . . So much money is spent on Sputniks it makes people gasp. If there were no Sputniks the Government

could cut the cost of cloth for an overcoat in half and put a few electric flatirons in the stores. Rockets, rockets, rockets. Who needs them now? [53]

Neither edition of Yeager's staff report spoke explicitly about Project Mercury, but both implicitly illustrated Mercury's motivation. The author delineated in lay language five categories of values served by national space programs. Intangible values came first and included scientific curiosity and the human urge to do as well as to know. National security was second, and included the argument for space rivalry as a substitute for war. Economic benefits, immediate and remote, were described in social terms for the third category. "Values for everyday living" described some of the technological and medical "fallout" or "spin-off" from space-related research. And finally this pamphlet pointed to long-range values and to possible interrelationships with the population explosion, water shortages, soil erosion, new leisure time, and the scientific and spiritual aspirations of humanity. In conclusion Yeager chose to quote a paragraph, from an editorial in the magazine *Industrial Research,* which "sober study indicates . . . may not be too 'far out' after all":

> Space technology is probably the fastest moving, typically free enterprise and democratic industry yet created. It puts a premium not on salesmanship, but on what it needs most—intellectual production, the research payoff. Unlike any other existing industry, space functions on hope and future possibilities, conquest of real estate unseen, of near vacuum unexplored. At once it obliterates the economic reason for war, the threat of overpopulation, or cultural stagnation; it offers to replace guesswork with the scientific method for archeological, philosophical, and religious themes.[54]

## Technical Sprint for Man in Space

Although election year reexaminations and premonitions of the Soviet Vostoks were disconcerting, these were the least of the conscious worries of the men teamed in the technological harness to get a Mercury astronaut off the ground. They still had a plenitude of more prosaic problems of their own. The inexorable growth of the capsule weight, the marginal performance of the Atlas as a launch vehicle, interface wiring and structural problems, and the worrisome reaction and environmental controls for the capsule were outstanding. On the other hand, some problems, like thermal protection during atmospheric entry and the physiological effects of weightlessness for a short period, were assumed solved for the moment.

Benjamine J. Garland, one of Faget's fellow authors of the seminal 1958 NACA paper for Mercury, prepared a special report for Gilruth on the probability of damage to the capsule by micrometeoroids during an orbital flight. Garland advised that the danger to the capsule during an orbital flight from sporadic meteoroid activity was very small. He calculated probabilities of hits during a major meteoroid shower and found the danger was "still small but . . .

an order of magnitude greater than the danger due to the sporadic background. Since the periods of activity of the major showers are known, it is possible to avoid operations during these periods and would be advisable to do so." [55]

Because qualification and reliability tests on the retrograde and posigrade rocket systems proved disappointing in their later results, Gilruth's team called for help from the Ames and Lewis Research Centers. Robert R. Nunemaker led a group at Lewis, monitored by John B. Lee of STG, who found some serious difficulties with retrorocket alignment and escape tower separation. Among other things, they found that some igniters were faulty and that the jettisoning of the escape tower under certain conditions might permit a smashing recontact.

But the most serious problem with capsule systems at this time was the outside chance that one or more of the three retrograde braking rockets might fail. There was considerable margin for error in the design of the retropackage, but there was no emergency braking system. STG's mission analysis group under John P. Mayer had thoroughly investigated an inflatable balloon for this purpose, and Gilruth himself proposed an emergency brake that would have looked like a Chinese dragon kite trailing in the wake of the orbiting capsule. This auxiliary drag device to back up the retrosystem and to bring the capsule down sooner than in the 24 hours theoretically required for a normal decay of Mercury's orbit was independently appraised by Howard K. Larson and others at Ames. Meanwhile John Glenn and the other astronauts asked STG's mission analysts to study the effectiveness of a "fish-tailing" maneuver as a backup reentry mode of last resort. Both ideas were reported feasible, but the former was not pursued past the end of the year, when the reliability of the retrorockets and pyrotechnics began to rise appreciably.[56]

Among the number of unsolved problems regarding man-machine integration in late 1960, the complex final phase of the mission profile aroused much concern. If an astronaut could survive launch, insertion, orbiting, reentry, and the free-fall, nothing must jeopardize his chances to survive impact, exit from the capsule, and recovery. But as the capsule developed into flight hardware, the differences between its theoretical design and its measurable performance required constant restudy, redesign, and in some cases redevelopment.[57] While studying the Mercury capsule's stability in water, for example, Peter J. Armitage and E. N. Harrin of STG found that the deletion of the flotation bags and the addition of the impact skirts had seriously compromised the floating trim if not the seaworthiness of the capsule.[58]

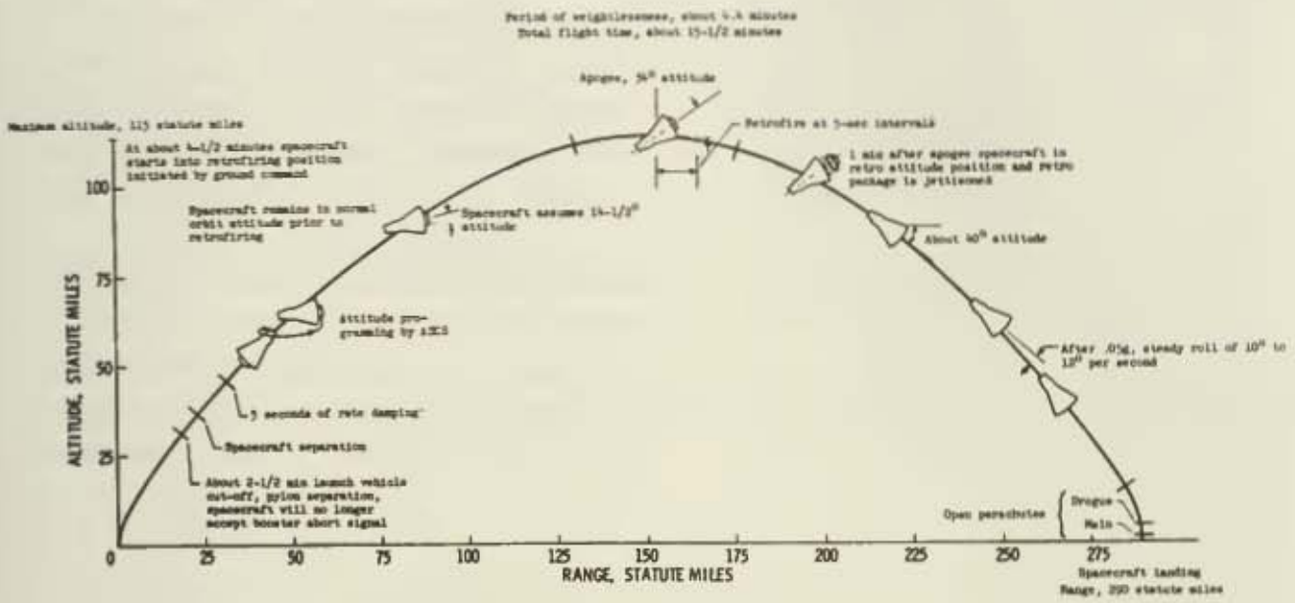
After summarizing recent investigations by both McDonnell and STG engineers, Armitage and Harrin pointed out a number of unknowns and recommended close scrutiny of any changes to capsule center-of-gravity positions to keep the capsule within acceptable stability limits. While the model-makers at Langley were fabricating and testing 24 new impact skirts, Astronauts Shepard, Grissom, and Schirra practiced getting out of the capsule; it now listed at severe angles and sometimes even capsized.[59]

During September 1960 all the Mercury astronauts began to train more pointedly for the Mercury-Redstone mission. Early in October they gathered their personalized couches, pressure suits, and accessories for centrifuge runs at the Navy's Aviation Medical Acceleration Laboratory at Johnsville, Pennsylvania. Fitted with a production handcontroller assembly and environmental control system, the gondola of the centrifuge whirled each man as if he were experiencing the calculated acceleration profile of the MR–3 flight. At Johnsville the astronauts gained experience in attitude and rate control, monitored the normal sequencing functions, and learned to cope with emergency conditions like overacceleration and decompression. Alan Shepard, for instance, took 10 training "flights" during the October session.[60]

On September 8, 1960, Silverstein called to Washington NASA's and McDonnell's chief engineers at work on Mercury to discuss plans for compressing the Mercury-Redstone schedule by expediting the capsule systems tests and checkout procedures for capsules Nos. 5 and 7, to be flown on MR–2 and MR–3, respectively. Once again Silverstein asked that McDonnell assign independent systems engineers to verify all hardware installations. Especially they were to improve the quality of capsule No. 7 before the formal systems testing period. This was done during October and November; for 43 days No. 7 underwent performance trials of all its systems except its reaction controls, automatic stabilization controls, and instrumentation and communications gear. McDonnell, Navy, and STG liaison inspectors tried hard to meet Silverstein's Cape delivery deadline of November 15, but two major discrepancies could not be allowed to pass. One problem had been perennial: overheating DC/AC inverters. Investigations disclosed that as long as the ambient temperature was kept below 165 degrees F they functioned properly. McDonnell attempted to cure this overheating problem by replacing the honeycombed inverter sockets with aluminum shelves that doubled as heat sinks.[61]

The second problem was new: tiny cracks were noticed in the outer titanium skin of the capsule pressure vessels. Samples of fractured material were sent to the Battelle Memorial Institute, an endowed foundation for applied scientific research, at Columbus, Ohio. Battelle found that the heated zones adjacent to the seam welds contained an excessive amount of precipitated hydrides, compounds of hydrogen and other elements. These impurities lowered the ductility of the skin of the pressure vessel, increased leakage rates, and increased the danger of structural collapse upon impact. But since capsule No. 7 had the best record of all in the capsule systems tests, it passed muster to begin its final factory shakedown tests on November 21, 1960. For later capsules, welding methods, vibration testing, and microscopic inspections were improved, but the long-standing "skin-cracking" problem required that the search be renewed for ways to eliminate hydride formations near the beads of fusion welds.[62]

On December 1, 1960, Jerome B. Hammack, the MR–3 project engineer for STG, and his assistant, James T. Rose, certified that capsule No. 7 was ready for




*Normal sequence of events for Mercury-Redstone flight.*

its manned mission, though some 20 days behind schedule. "The writers would like to stress that the majority of time spent during this period was spent on correction and rework rather than the actual CST and that every effort should be made in the future to achieve manufacturing perfection prior to the capsule entering CST." [63]

Meanwhile capsule No. 2, being readied for the first Mercury-Redstone flight, was delivered to the Cape at the beginning of August. This flight, MR–1, was then scheduled for launching early in October. Both McDonnell and STG preflight checkout crews in Hangar S worked around the clock to make ready the maze of systems in their capsule. Christopher Kraft talked over Mercury command functions with the Redstone launch team under Debus and with Air Force range safety officer Lieutenant Colonel R. D. Stephens early in September. They then decided to fly the MR–1 mission with the automatic abort system in the open-loop mode to lessen any possibility of a nuisance abort on this qualification flight.

On a trial basis, a smaller Flight Safety Review Board for the spacecraft (tailored after the Atlas boards by the same name), chaired by Walter Williams and consisting of Astronaut Cooper, F. J. Bailey, Jr., Kenneth S. Kleinknecht, and William M. Bland, Jr., was established at the Cape to pass final judgment during the week before the countdown on the readiness of the mission. During the first week in October, final preparations were made to launch MR–1, and on the morning of October 9, 1960, an unbroken countdown proceeded to within 22 minutes of launchtime before the shot was scrubbed because of a malfunction in the capsule reaction control system.[64]

By the first of November both LJ–5 and MR–1 appeared ready for launching on November 7, 1960. But both launches had to be postponed again (the day before the election) because of inclement weather at Wallops Island and because at the Cape a serious leak developed in the helium tank of capsule No. 2. Without helium to pressurize the hydrogen peroxide thrusters, the payload after posigrade release might not reorient itself properly for reentry. So heavy had the workload at the Cape become that Williams decreed a maximum of 12 hours' work for any one person in any one day.[65]

The possible political significance of these launches now was seen by the press and by the legislative staffs on Capitol Hill and at NASA Headquarters. George Low's routine report for James P. Gleason, Assistant Administrator for Congressional Relations, carefully explained the technical reasons first for delay and then for speedup on the launch schedules. Regarding Little Joe 5, Gleason informed the staff director of the Senate space committee that NASA Headquarters was keeping close tabs on MR–1 scheduling information because of the need to coordinate interagency activity, but that Little Joe missions "requiring no major coordination with non-NASA organizations" had always been handled on a less formal basis:

> You will notice that the launch target date was delayed from October 8, 1960, to November 11, 1960, at the time when it became apparent that the capsule delivery would be delayed until about August 1, 1960. Between August 17 and August 31, a large number of checkout difficulties was encountered in the noise and vibration test program. It was then expected that the capsule would not arrive at Wallops until October 5, and hence the launch date was moved to November 16.
>
> In the early part of September, the rate of progress at Langley picked up, and the capsule was actually shipped to Wallops on September 27th. Nevertheless, the projected launch date was not moved to an earlier date, since simultaneous experience with MR–1 at Cape Canaveral gave every indication that the prelaunch checkout would take longer than planned.
>
> In actual practice, the Wallops Island checkout ran very smoothly. Accordingly, a new target date of November 7 was established late in October. Barring difficulties during the final checkout period, and assuming that the weather will be clear and calm, the launching will take place on that date.
>
> . . . I feel that our project engineers have done an excellent job at predicting these dates; it is very seldom that actual dates on as complex a research and development program as this one have come out so close to the predicted dates as these have.[66]

Less out of sensitivity to the political winds than because the facts seemed to warrant it, the apolitical civil servants in the Task Group sent an encouraging status report on Project Mercury to their administrative superiors in Washington at the end of October 1960. There were a couple of negative items: the cause of the MA–1 failure was still unknown, and the checkout time at the Cape for capsule No. 2 for MR–1 was stretching interminably, it seemed. On the plus side, three capsules (Nos. 2, 5, and 6 for MR–1, MR–2, and MA–2, respectively) were on hand, and two more (Nos. 7 and 8 for MR–3 and MA–3) were expected

at the Cape momentarily. The Mercury Control Center, a command-post building trisecting the area between the two blockhouses beside the launching pads and the industrial hangars, was open and almost ready for operations. Four preflight checkout trailers supplied by McDonnell were already in full use. Procedures Trainer No. 2 was being wired to its computer banks, and the ground-test qualification program seemed almost complete.

The tracking and communications network was essentially finished, except for the stations at Kano, Nigeria, and on Zanzibar. The Atlas ASIS was looking good, and with luck the first truly complete Mercury-Atlas configuration, MA–2, still might possibly be flown during the quarter. Cost accounting for the program was still a black art, but according to STG's own estimates the summary of funds required to accomplish the Mercury mission as defined in October 1960 approached $110 million: [67]

| | |
|---|---|
| Mercury capsules (20) | $48,720,000 |
| Mercury boosters | 25,429,000 |
| Mercury network (incl. operations) | 18,953,000 |
| Mercury recovery (incl. operations) | 10,573,000 |
| Biological and human engineering | 1,922,000 |
| Development program | 3,928,000 |
| Total | $109,525,000 |

## Little Joe 5 Votes No

On Election Day, November 8, 1960, Space Task Group and McDonnell engineers at Wallops Island finally pulled the trigger on capsule No. 3, attached to Little Joe 5. Having planned LJ–5 for over a year as the first qualification flight of a production capsule to sustain abort conditions at maximum dynamic pressure, the hard-working crews were especially chagrined to see the disintegration of all their plans only 16 seconds after liftoff. At that time the escape rocket and the tower jettison rocket both prematurely ignited while the booster was still thrusting. Therefore booster, capsule, and tower stayed mated together throughout their ballistic trajectory until impact shattered them to fragments.

Whether the limit switches at the clamp rings below or above the spacecraft were at fault, or whatever improper rigging, wiring, or voltage regulation was the cause, it was exceedingly hard to rationalize that something was learned from this flight failure. Spacecraft and booster continued on their arc 10 miles high and 13 miles out to sea before being mangled on impact 2 minutes later. Salvage operations in water 72 feet deep recovered 60 percent of the booster but only 40 percent of the capsule.[68] Extensive tests on the clamp-ring problem were conducted on rocket sleds at the Naval Ordnance Test Station at Inyokern, California.

For well over a year Holloman Air Force Base personnel, led by Major John D.

Mosely, of the Aeromedical Field Laboratory, had prepared a packaged payload with a medium-sized chimpanzee to ride the LJ–5 qualification flight. As late as mid-July 1960, operational planning still included a first-order test objective to determine the effects of a simulated Atlas abort acceleration on a chimp. The delay in capsule delivery and a large number of checkout difficulties encountered in late August, especially with the booster-capsule clamp rings and pyrotechnics, led William Bland and Rodney G. Rose to persuade Gilruth to rule out the primate on Little Joe 5. Besides that, the second Mercury-Redstone now being groomed for a chimp flight represented a direct conflict in scheduling.

As disappointing as this decision was to aeromedical personnel, including James P. Henry, the physician who supervised the animal program for STG, the managers of the Task Group felt they could not afford to risk further delays. The structural integrity of McDonnell's Mercury capsule and the escape system during that most critical time in the region of highest dynamic pressure had to be demonstrated as soon as possible. By deliberately omitting the environmental control system and its problems, the Task Group had hoped to concentrate on hardware dynamics, taking extraordinary precautions "to minimize premature firing of any of the capsule pyrotechnics on the launching pad." [69] Obviously something—no one knew what—had been overlooked.

After the dismal failure of Little Joe 5, these bleak days for Project Mercury became even bleaker with the discovery that the helium leak in the capsule for MR–1 could not be fixed quickly; it would require the replacement of certain valves and the whole hydrogen peroxide tank. Furthermore a change in the MR–1 wiring was dictated by the poor sequence and circuitry design on Little Joe 5. NASA had one more Little Joe test booster on hand. One more airframe, the last one in existence, had recently been ordered as a backup to the next shot. On November 10, NASA Headquarters was reassured that a stripped capsule on the backup booster could fulfill the Little Joe 5 mission, "an essential one before manned flight," probably before the end of January. And both Mercury-Redstone 2 and Mercury-Atlas 2 still were considered "not beyond the realm of possibility" for launchings in December.[70]

There was precious little in Mercury to be thankful for during the Thanksgiving season of 1960, but there was more than enough work to keep everyone in STG preoccupied. Caldwell C. Johnson wrote Faget a summary memo concerning the capsule's weight growth and its effect upon Atlas performance and mission profiles. While McDonnell was conducting extensive tests of the impact skirt situation, Johnson and others were worried about whether it would ever work. In the light of later developments, the ferment over redesign at this time became significant, and Johnson's words grew in significance:

> We have been monitoring Mercury weight growth, McDonnell's airplane-weight history and the X–15 weight versus development phase and conclude that Mercury orbit weight by the time of manned flight will exceed 3000 pounds! Capsule weight during parachute opening mode will be 2600 pounds;

flotation weight is practically as great. These increases have a detrimental effect upon orbital insertion probability, retrograde action, parachute opening loads, and water stability. The only single action that will cure the problem is weight reduction in the capsule but its weight growth is inexorable. It appears that several separate actions are necessary.

J. Mayer calculates that at 3000 pounds the probability of orbit insertion is less than 96 percent even when based upon certain Atlas performance increases. Furthermore, the possibility of an African landing from an early abort is very real. He says there are some reasons to believe that Atlas weight can be further reduced and greater payload capacity realized but so far this is but speculation, and, in any case, doesn't do much for the African landing situation.

Some time ago increased retrograde capability was proposed but could not be justified at that time. There is little doubt that such a change is justified now—the question is whether posigrade impulse should likewise be increased to aid orbit insertion. It is tempting to combine posigrade and retrograde systems and to utilize the propellant as required by the particular flight situation. But, this is a rather drastic change.[71]

## MR–1: The Four-Inch Flight

November 21, 1960, marked the absolute nadir of morale among all the men at work on Project Mercury. That was the day the MR–1 countdown reached zero, and when "all we did was to launch the escape tower."

Capsule No. 2 had been checked out at Huntsville on July 21 and shipped to the Cape the next day. The final standard trajectory was published on August 1, and the Redstone booster was delivered two days later. From July 23, when the capsule was airlifted to the Cape, until October 7, extensive internal reworking was required. Since this was the first complete capsule to be subjected to preflight checks, it was impossible to know precisely how long the checkout would take. Gleason of NASA Headquarters had explained these scheduling gymnastics to the Senate committee staff on November 3:

Between October 6 and October 31, 1960, the work proceeded exceedingly well. By October 24, for example, first mate had been completed. The rework had been accomplished and the simulated mission and servicing had been carried out. Not only had none of the contingency period been used up, but preparations were actually two days ahead of schedule! It was, therefore, hoped for the first time, that the working level target date might actually be met, assuming that some as yet unresolved electrical troubles would not cause any real delays.

On October 31, the final mating of the capsule and booster was accomplished. Still two days ahead of the target date established on October 7. Therefore, it became clear, upon examination of the remaining work, that the launching might take place on November 7. Accordingly, the Project Mercury operations director requested range clearance for November 7 and also requested support by Naval recovery forces for this date.

Because of the continuing great urgency of Project Mercury, and because each succeeding launching hinges critically on the dates of previous launchings, the selection of November 7 as a launch date for MR–1 was the only possible

course of action to take for the operations director. In making this decision, he recognized that he was merely identifying the earliest possible launch date, and that this date might well be delayed if difficulties were to be encountered during the final checkout, or if bad weather was encountered. A later decision, on the other hand, would have been inexcusable for this might have caused unnecessary delays if all went well during the final checkout period.[72]

MR–1 was on the launch table on November 7, 1960, when the helium pressure dropped from 2250 pounds per square inch to 500 pounds in the capsule control system, and the mission was scrubbed again. The capsule was removed from its booster and the heat shield was removed from the capsule so that a helium relief valve and the toroidal hydrogen peroxide tank could be replaced. A wiring change was made to avoid a failure of the Little Joe variety, and electrical sequence checks were redone as reassembly proceeded. Then, on November 21, MR–1 was reassembled and the final countdown proceeded normally, with the exception of a one-hour hold to fix another leak in the capsule's hydrogen peroxide system. The Mercury Control Center was manned for the first time. At 9 a.m. Redstone ignition occurred precisely as scheduled.

The expected blast momentarily churned the air around launch complex No. 56. But then the roar stopped as suddenly as it had started. Watching by periscope from the blockhouse, the startled engineers saw the booster wobble slightly on its pedestal and settle back on its fins after, at the very most, a four-or-five-inch liftoff. The Rocketdyne A–7 engine shut down, and the escape pylon zipped up 4000 feet and landed about 400 yards away from the launch site. Three seconds after the escape rocket blew, the drogue package shot upward, and then the main chute spurted out of the top of the capsule followed by the reserve parachute, and both fluttered down alongside the Redstone.

Mercury-Redstone 1 was the most distressing, not to say embarrassing, failure so far in Project Mercury. Critics waxed unrestrained. Even the Redstone experts seemed disconcerted.[73] Technically it seemed inexplicable that the normal, instead of the abort ejection, sequence had followed engine shutdown. George Low later that day carried STG's report to the NASA Headquarters staff on what they thought had happened:

Apparently, sufficient thrust had developed to lift the booster at least $\frac{3}{32}$ inch, thereby activating all the systems. (This would require more than 85% of nominal thrust.) The booster settled back down on the pad, damaging the tail fins, and perhaps the structure as well (some wrinkles are visible in the shell). The reason for this shutdown is unknown—the only shutdown to the booster could have come from the booster programmer, at the end of the normal flight sequence. Just how this programmer malfunctioned cannot be determined without a detailed inspection.

The capsule sequence . . . was a normal one for the type of signal it received. A closed-loop abort sensing system would have given an abort signal under the conditions of this launching, carrying the capsule away in a regular off-the-pad abort sequence.

At the time of this writing, the booster destruct system is still armed, and

cannot be disarmed until the battery depletion during the morning of November 22. Capsule pyrotechnics (including posigrade and retrograde rocket) are also armed. The problem is further complicated by the fact that the main parachute is still hanging from the capsule; thus the booster could be blown over in a high-wind condition. Weather predictions, however, are good. It is planned to put the gantry around the booster in the morning, under the assumption that the Redstone has not shifted sufficiently to make this impossible. This will be followed by booster and capsule disarming and sequence checks to determine the cause of the failure.

The extent of damage to the capsule has not yet been assessed. Assuming a minimum of damage, it is planned to use the same capsule, together with the MR–3 booster, for the MR–1 firing. It will probably take a month before this launching can take place.[74]



**MR–1**
**Nov. 21, 1960**

*Mercury-Redstone 1 has just "blown its stack" on the launch pad, seconds after ignition. After, at most, a four-or-five-inch liftoff, MR–1 launched its escape tower but not the capsule. Then followed the normal flight sequence of parachute deployment. The drogue chute is shown here deploying just after ejection of the antenna canister. A few seconds later would come the main and reserve main parachutes.*

The day after the MR–1 attempt, Walter Burke of McDonnell volunteered to lead a squad of men to disarm the pyrotechnics and umbilical cable still hanging fire. Two days later, after intensive on-the-scene investigations of the puzzle presented by MR–1, Low reported a better consensus of expert opinion:

> The MR–1 failure is now believed to have been caused by a booster tail plug which is pulled out about one inch after liftoff.
>
> It has been determined that this two-prong plug is designed so that one prong disconnects about one-half inch before the second one does. This time interval between disconnect of the first and second prongs for MR–1 was 21 milliseconds.
>
> The booster circuitry is such that if one of these prongs is disconnected prior to the other and while the booster is not grounded, a relay will close giving a normal engine cutoff signal. The time interval between successive disconnects was apparently just sufficient to allow the relay to close.
>
> It is reasoned that Redstone missiles are somewhat lighter than the Mercury Redstone (with its extended tank), thereby giving higher initial acceleration and shorter time intervals between disconnects between the two prongs. This shorter time interval would be sufficient to allow the relay to close, thus having avoided this type of failure in the past.
>
> This relay behavior could not be detected during checkout procedures since it will only occur when the booster is not grounded.
>
> The above theory of failure was advanced by Marshall personnel at Cape Canaveral and has not been confirmed by Marshall-Huntsville. It is planned to continue tests at Huntsville using the Mercury-Redstone No. 2 booster to verify this hypothesis.[75]

Within a week, MR–1 was rescheduled for December 19, and MR–2 and MR–3 had been postponed until 1961. Low informed Silverstein that "The MR–1 capsule will be used as is, together with the escape tower from Capsule 8, and the antenna fairing from Capsule 10. The MR–3 booster will be used for this shot." [76] There was no longer any question that the mating of booster and spacecraft should be done at the Cape.

Physicists observing MR–1 might have expected someone among the 5000 members of the Marshall Center to have guarded against the relativity of simultaneity where electrical signals were concerned, but McDonnell and Task Group engineers dared not taunt their fellow workers on the Redstone about the cause of the "four-inch flight" of MR–1. They were happy that the sequence system on the capsule performed perfectly, but they too felt responsible for the failure of the MR–1 capsule to abort. Meanwhile Joachim P. Kuettner and Earl Butler at Huntsville, and Kurt Debus and Emil P. Bertram at the Cape, frantically drove the men of their respective Redstone-Mercury Office and Launch Operations Directorate to hasten preparations for MR–1A. By mid-December 1960, the Redstone team assured Washington that the repeat flight was almost ready:

> The November 21 type event will be avoided, in the future, by the addition of a ground cable sufficiently long to maintain a good ground connection until all umbilical plugs are pulled. In addition, the booster circuitry has been

> modified so that a cutoff signal can only get to the capsule after 130 seconds of booster thrust (normal cutoff occurs at 140 seconds). Before that time, the capsule can only be released from the booster through an abort signal, manually given from the ground.[77]

Minor additional improvements were made to the capsule systems, a revised master operational schedule was issued, the Mercury ground control operations team was brought up to full strength, and Jerome Hammack, STG's Redstone project engineer, along with Paul C. Donnelly, the Mercury-Redstone test conductor in the blockhouse, worried through each day, hour, and minute before December 19.

### MR–1A: Suborbital Quality Proven

Early in the morning of December 19, winds of 150 knots aloft in the jet stream required a 40-minute hold. During the countdown another solenoid valve in the capsule's hydrogen peroxide system had to be replaced, necessitating a recycle of the count by one hour. So it was 45 minutes before noon when the dramatic final 10 seconds of countdown for MR–1A occurred. This time there were no fouls. The 83-foot Mercury-Redstone assembly was cheered on—"Go! Fly, bird! Go!"—as it lifted off, burning brightly for 143 seconds to a velocity (slightly high) of 7120 feet per second at cutoff. With this impetus, MR–1A coasted on up to 131 miles, its maximum altitude, then nosed over while the bolts in the mating-ring exploded as planned and the booster and its payload parted company. The capsule behaved perfectly in its attitude control and came down along its predestined trajectory to impact 235 miles from Cape Canaveral, 18 miles beyond the desired target impact point.

A P2V aircraft pilot saw the capsule descending on its parachute at 4000 feet, and about 35 minutes after launch a Marine helicopter from the aircraft carrier *Valley Forge* retrieved the capsule, and returned it secure to the flight deck of the carrier within 48 minutes from launch. This time Low elatedly reported to Glennan that "the launching was an unqualified success."[78]

The Goddard Space Flight Center computers, both men and machines, performed admirably in making their first "real-time" impact prediction. On the *Valley Forge* sailors crowded everywhere topside. Visual inspections of the capsule by a NASA recovery inspection team revealed no damage except a crack in one outer layer of glass in one capsule porthole.

Exuberance was obvious in the postlaunch reports of the various participants. Howard C. Kyle, the capsule communicator, said, "Except for a few minor discrepancies during the countdown, all equipment appeared to operate normally. Technical support was universally superb." Tecwyn Roberts, the flight dynamics officer, wrote, "All communications checked A. OK. Data selection loop had some noise, but intelligible communication was possible at all times." Henry E. Clements, a captain in the Air Force and network status monitor, reported all




## MR–1A
## Dec. 19, 1960

*Mercury-Redstone 1A, the repeat flight to Mercury-Redstone 1, was successfully undertaken 28 days later, on December 19, 1960. The electrical ground cable that had caused the failure of MR–1 had been lengthened. Here, during loxing for a flight readiness test, frost shows on the rocket and steam on the ground. Slight overacceleration of both this and the MR–2 booster caused an extra Redstone flight to be inserted in the Mercury schedule. The recovered spacecraft is shown below the day after the flight at the Cape being inspected by Charles J. Donlan (left), Robert Gilruth, and Maxime Faget; it came through the brief flight in excellent condition.*



instrumentation "A. OK," with few discrepancies. One note of caution was entered by Stanley C. White, the Mercury Control Center flight surgeon:

> The acceleration associated with the reentry exceeded by at least 1 g the calculated value. If a similar overshoot occurs with the new profile being proposed on future MR flights, we are reaching the point where the astronaut has demonstrated inability to stay alert and to keep up with the events. The consequence of this aberration from predicted should be discussed before the new profile is accepted.[79]

Later, when the movies from the onboard camera were developed and shown, clean-room engineers and workers saw the necessity for still higher standards of cleanliness. Washers, nuts, and wire clippings came out from hidden niches and floated freely around the cabin during the weightless period. But otherwise, the Mercury team felt the pendulum of luck beginning to swing back in their favor at the end of 1960. They were proud of the Christmas gift represented by the demonstration of suborbital capability of the hardware in MR–1A.

Perhaps the most significant result of the Little Joe 5 and MR–1 failures was a profound reexamination among the managers of Project Mercury of their original design philosophy. Warren North reported to Silverstein at Headquarters on December 6 the results of a series of discussions among field hands on the subject of man-machine integration:

> During the week of November 27, Messrs. Gilruth, Williams, Mathews, Preston, Bland, Ricker, Fields, Roberts and others conducted a major review of the capsule and booster sequence logic in an effort to determine what improvements could be made to prevent incidents such as occurred during Little Joe 5 and MR–1. Also involved in the week long series of discussions at Cape Canaveral were key personnel from McDonnell (including Burke), Convair, Marshall, and Aerospace.
>
> As a result of operational experience, it was apparent that some of the original design philosophy should be changed, especially insofar as the role of the pilot is concerned. It has become obvious that the complexity of the capsule and booster automatic system is compounded during the integration of the systems. The desirability of avoiding, for manned missions, a direct link between capsule and booster systems, is therefore being studied. For example, the Little Joe-type failure would be averted by the use of an open loop manually controlled abort system. Similarly, the escape tower would not have jettisoned during the MR–1 launch attempt if this had been a manned flight with manual control over the escape rocket and capsule sequence system.[80]

Meanwhile the Atlas, the basic vehicle to propel Mercury into orbit, also was undergoing its most critical examination. A special ad hoc technical investigating committee, established on December 19, 1960, composed of both NASA and Air Force personnel, and headed by Richard V. Rhode of NASA Headquarters and Colonel Paul E. Worthman of the Ballistic Missile Division, was ordered to investigate the reasons why the Atlas had failed so often on NASA launches. Called the Rhode-Worthman Committee informally, the dozen members, rep-

resenting all concerned organizations, looked carefully at three recent failures in the Atlas-Able series of lunar probes, at MA–1, and even at Big Joe, hoping to prevent another fiasco. Since the conferees at the last major coordination meeting, on November 16, had issued a test program summary reviewing MA–1 and subsequent action, the Rhode-Worthman group began with those inconclusive records and a set of 12 agreements on launch conditions for MA–2. Paul Purser and Robert E. Vale flew to Los Angeles the day after Christmas to defend STG's position on MA–1 and to expedite Convair's construction of a "quick-fix" solution for MA–2 and its fabrication of "thick-skin" Atlases for subsequent Mercury flights. Other members of the committee distrusted the original design for the "quick fix," which was in the form of a "belly band," or girdle, to strengthen the interface area around "station 502" on the Atlas booster, where the adapter ring for the capsule nested against the lox dome. Later the dissenting committee members supported a revised version of the fix after a number of their suggestions had been integrated. Both Chamberlin and Yardley had suggested the "belly band," but Hohmann disagreed. On December 31, 1960, Purser warned Charles Donlan, back at Langley Field, that STG and Convair might be overruled by Aerospace, STL, BMD, and NASA Headquarters representatives. As it turned out, on the second day of the new year Rhode sent a message to Seamans at NASA Headquarters that recommended great caution regarding the decision to incorporate the "quick fix," as many of the committee felt that it added uncertainty and possibly a new set of hazards. If so, MA–2 might have to wait three to six months more for a "thick-skin" Atlas from the factory.[81]

The year 1960 ended in suspense for the Mercury team. The Soviet attempt on December 1–2, 1960, to orbit and retrieve two more dogs from space had, as the Soviets admitted, ended in cremation for "Pchelka" and "Mushka" when their attitude control system failed at retrofire and their vehicle, *Korabl Sputnik III,* burned up on reentry from its rather too shallow orbit. To appraise the meaning of the flight of the Soviets' third man-sized spaceship from available information was exceedingly difficult. Obviously the Soviets were close to the day when they could put a man into orbit, but the similar failures of their first and third "cosmic ships," on May 19 and December 2, respectively, had made the question "How close?" highly debatable.[82]

On December 5, a member of the Soviet Academy of Science, G. Pokrovsky, had extolled the "socialist system," in spite of its failure to recover Pchelka and Mushka, and boasted that "we are on the threshold of manned space flight, and the first man to be in space will undoubtedly be a Soviet citizen." That same day, *Time* magazine had bemoaned "Lead-Footed Mercury" and ridiculed Wernher von Braun's calling MR–1 "a little mishap": "Project Mercury's latest failure, third in a row, just about evaporated the last faint wisp of hope that the U.S. might put a man into space before Russia does." A *New York Times* editorial agreed with that evaluation and advised the new President-elect to persevere: "The first man in space will not be the last, and after the tributes have been paid

to that first man and those who made his feat possible the more important question will arise of what man can do in space that is worth the immense cost of putting him there." [83]

Although there was some exultation in the United States after the success of MR–1A on December 19, the public seemed to sense, without any deep understanding, a difference of several orders of magnitude between Soviet space flight tests and American qualification flight difficulties. Within the Space Task Group, NASA, and the Mercury team, technical understanding, sometimes divorced from political intuition, appeared to buttress the hope that an American manned ballistic flight into space might still precede the substantially more difficult manned orbital flight around Earth. Manned space flight was a name for a series of field events in the space olympics. Although the odds were with the Soviets to win the marathon of the first orbital circumnavigation, perhaps Mercury might win the suborbital sprint.

# X

# Tests Versus Time in the Race for Space

(JANUARY–APRIL 1961)

ON January 3, 1961, two years and three months after it was formed, the Space Task Group officially became a separate, autonomous NASA field element charged with the conduct of Project Mercury and any other manned space flight programs that might follow it. The Task Group, now composed of 667 people, was still located physically on the Hampton Roads side of the Langley Air Force Base and was supported by the Langley Research Center, but now the administrative marriage of STG with the Goddard Space Flight Center in Beltsville, Maryland, was annulled.[1] The Mercury team had not yet managed to launch a manned rocket, but neither apparently had their Russian counterparts. The United States still had a good chance to place the first man in space, at least for five minutes. The Soviet lead in orbital flight tests argued heavily against the first manned satellite being American, but to score first would still be some consolation.

In only three years and three months since *Sputnik I,* the Soviet Union and the United States had launched into space a total of 42 vehicles, 38 of which were Earth satellites, three were solar satellites, and one was a lunar probe. The box score in the "space race" between the United States and the Soviet Union was 33 to 9 in favor of the home team, as far as publicly successful space launchings were concerned. But with only nine acknowledged launchings the U.S.S.R. had hoisted some 87,000 pounds (as opposed to the U.S. total of 34,240 pounds), the Soviets had hit the Moon and photographed its backside, and they had recovered two dogs from one Earth orbital flight. Of the 33 American space launches, only three had been done by NASA launch vehicles and crews. Of the remainder, 24 had been launched by Air Force rockets, five by Army boosters, one by the Navy. In contrast to the responsibility for launching these 31 Earth satellites and two solar satellites, the credit for building the instrumented payloads was spread more widely; the Air Force counted 15 successes, the Army and Navy four each, and NASA 10 spacecraft. Already the complexity of accounting properly for mankind's successful satellite and space probe projects was reaching formidable proportions.[2]

On January 11, 1961, three Soviet tracking ships were reported moving into the central Pacific once again. The next day, in his final State of the Union address, President Eisenhower commended the young space administration for its "startling strides" and "real progress toward the goal of manned space flights." After listing all the successes of American instrumented payloads in space, Eisenhower said:

> These achievements make us unquestionably preeminent today in space exploration for the betterment of mankind. I believe the present organizational arrangements in this area, with the revisions proposed last year, are completely adequate for the tasks ahead.[3]

At this same time, President-elect John F. Kennedy announced that Jerome B. Wiesner of the Massachusetts Institute of Technology, who had chaired the Democratic science advisory committee for the campaign, would become the new Presidential special assistant for science and technology. And with this announcement Kennedy released most of a special report made to him by Wiesner's committee of nine campaign advisers on the state of the Nation's security and prestige. A political document, the "Wiesner Report" called for a sweeping reorganization of the national space program. It was critical of past leadership and direction, and it called for more effective use of the National Aeronautics and Space Council, better coordination with the Department of Defense, stronger technical management, and a closer partnership with industry. On top of all this came the uncorroborated news that an Army officer had told a seminar of almost 500 civilian and military participants that the United States had good evidence that at least one and probably two Soviet cosmonauts had been killed in unsuccessful attempts to orbit a man during Premier Khrushchev's visit to the United States in September 1960.[4]

## Interregnum

On January 16, 1961, President Eisenhower delivered his annual budget message to Congress, asking for amendments to the Space Act of 1958 and referring to Project Mercury with far less confidence than he had shown five days earlier:

> In the program for manned space flight, the reliability of complex booster, capsule, escape, and life-support components of the Mercury system is now being tested to assure a safe manned ballistic flight into space, and hopefully a manned orbital flight, in calendar year 1961. Further testing and experimentation will be necessary to establish whether there are any valid scientific reasons for extending manned spaceflight beyond the Mercury program.[5]

Members of the Space Task Group and of the Mercury team at large could take little comfort from the fact that this speaker was an outgoing President, for they also knew that the incoming President's scientific policy adviser had been quite critical of the "marginal" Mercury-Atlas program. Regarding "man-in-space," the Wiesner Committee had said:

> We are rapidly approaching the time when the state of technology will make it possible for man to go out into space. It is sure that as soon as this possibility exists, man will be compelled to make use of it, by the same motives that have compelled him to travel to the poles and to climb the highest mountains of the earth. There are also dimly perceived military and scientific missions in space which may prove to be very important.
>
> By having placed highest national priority on the Mercury program, we have strengthened the popular belief that man in space is the most important aim of our non-military space effort. The manner in which this program has been publicized in our press has further crystallized such belief. It exaggerates the value of that aspect of space activity where we are less likely to achieve success, and discounts those aspects in which we have already achieved great success and will probably reap further successes in the future.[6]

When the managers of NASA and of STG, a few days later, became aware of the earlier, longer, confidential version of the Wiesner report, they were reminded of Mercury's tenuous standing as an urgent, but not an indispensable, "crash" program. If they should fail on their first attempt to place a man in space, or to put him in orbit, or to recover him from orbit, they not only would sacrifice a human life but create a national humiliation. Mercury managers had always been acutely aware of these portents, but the low status of Mercury in real and rumored policy papers made these days darker than ever. Wiesner's Committee recommended that Kennedy not allow "the present Mercury program to continue unchanged for more than a very few months," and that he not "effectively endorse this program and take the blame for its possible failures." Above all else the Wiesner Committee recommended that:

> *We should stop advertising Mercury as our major objective in space activities.* Indeed, we should make an effort to diminish the significance of this program to its proper proportion before the public, both at home and abroad. We should find effective means to make people appreciate the cultural, public service, and military importance of space activities other than space travel.[7]

Next to Mercury, the Wiesner group was most critical of the Nation's booster program, particularly of the inability of United States rockets to lift heavy payloads into space. Measured by rocket thrust, Russian superiority continued unchallenged. Profound criticism was levelled at the Atlas, which was now truly operational as a weapon system, but which had failed signally in its five most recent tests as a launch vehicle for NASA payloads. Wiesner's committee recommended vigorous study of the Titan missile as an alternative Mercury launcher, but STG had already studied and rejected the Titan as a launch vehicle.[8]

Whereas there seemed to be threats of cancellation or modification of Project Mercury from all sides, the Mercury teammates knew from their MR–1A experience of December 19, 1960, that nothing succeeds like success. While some of them carefully but hurriedly made ready for MR–2, others just as desperately sought to ensure the success of MA–2.

In moments of respite from its hectic pace, STG could see three essential tasks that had to be performed within a matter of weeks if the Task Group was to

be kept together and functioning. First was the necessity to send a chimpanzee on a successful Redstone flight. Second was the need to qualify the McDonnell capsule and all its systems by a Little Joe flight under max q conditions similar to the worst possible Atlas abort. Third, but perhaps most important, was the imperative need to test and prove as soon as possible the Mercury-Atlas combination, even if only on an elementary ballistic flight.[9]

The admittedly "hasty" Wiesner report was received by the press with mixed reactions. According to the *Washington Post,* the study was tacitly adopted by the President-elect when he named Wiesner, simultaneously with its release, Chairman of the President's Science Advisory Committee (PSAC) for the new administration. *Aviation Week* said that Kennedy had rejected the committee's advice to revamp or scrap Mercury and that he had decided to risk receiving the blame if the first manned shot failed. To Roscoe Drummond, a syndicated columnist, the Wiesner report read like "a melange of observations based on superficial study." Drummond was highly critical of the entire political transition, noting that T. Keith Glennan had departed from Washington on Inauguration Day, January 20, 1961, leaving NASA headless, since no one had yet been named as his successor. Hugh L. Dryden, too, had resigned in accordance with protocol, but he remained on hand until he should be relieved. Drummond further charged that no Kennedy representative had consulted NASA to study the workings of the agency nor had any Kennedy official read or listened to briefings that had been prepared for the new leaders by outgoing Administrator Glennan and his staff.[10]

In this time of transition NASA officials expected a stronger challenge to the civilian space agency's sphere of influence from the military, perhaps supported by some defense industry contractors. Part of the "military-industrial complex" against which Eisenhower had warned in his farewell address seemed to be lobbying to shrink NASA's function to that of the former NACA—applied research and development engineering.[11] The retiring President also had warned against the domination of science by the needs of the Federal government and against the domination of public policy by a "scientific-technological elite." On the other hand, the editors of *Aviation Week* had expressed alarm several times over NASA's tendency toward enlargement of its own technical bureaucracy and assimilation of other space research organizations.[12] Whether or not there was actually any "power struggle" among the Air Force, Army, and Navy over the spoils from a stripped NASA, any such fears of the Pentagon were premature while the Mercury-Redstone attempt to fly and recover an "astrochimp" was still pending.

For some time, NASA had endured attacks from various eminent American men of science. The Wiesner report both reflected and encouraged such attitudes. Vannevar Bush, James R. Killian, and George B. Kistiakowsky were all long since on record as considering manned space flight a technological luxury that ought not to be allowed to eclipse more urgent scientific necessities. Even

within NASA, some scientists would have reallocated resources for manned space efforts beyond Mercury so as to give more funds and priority to instrumented, more purely scientific, research flights.[13]

Such political opinions of scientists to a large degree had been translated into official policy under the Eisenhower administration, whose last budget recommended a manned space flight research and development cut of $190.1 million from NASA's request for fiscal year 1962 of $1,109,600,000. The Bureau of the Budget in January allowed a total NASA request of $919.5 million, only $114 million of which was earmarked for manned space flight, including Project Mercury. Some $584 million was requested for military astronautics within the total $41.2 billion request for the Defense Department's budget.[14] Surely this contrast in funding carried significant meaning.

The criticisms of NASA and its struggle for money in Washington were serious enough, but of far greater concern to the civil servants, contractors, and servicemen working with NASA and STG was the problem of "Mercury-rating" the Atlas. Since the unsolved MA–1 disaster at the end of July 1960 had been blamed on, but never isolated in, the interface area where the capsule and booster were mated, both the Air Force and NASA shared uneasily the responsibility for finding preventive medicine before MA–2 could be launched.

The Wiesner Committee apparently had been unaware of the Rhode-Worthman Committee, established on December 19, 1960, four days after the explosion of the Atlas-Able 5–D Moon proble. NASA and the Air Force, acutely aware of Wiesner's activity, were pressuring the high-level investigating committee of seasoned engineers to find solutions to the interface problem. NASA Headquarters was very much concerned by the poor performance of the lighter-gauge Atlas modified for NASA launches and by the inability of STG and the Air Force complex to pinpoint the reason for the MA–1 failure. Richard V. Rhode, NASA Headquarters' senior structural engineer, was sent to California to press for a solution. The Air Force Ballistic Missile Division, under Major General O. J. Ritland and Brigadier General H. W. Powell, likewise had appointed a senior technical officer, Colonel Paul E. Worthman, to work with Rhode as co-chairman.

During the last week of December 1960 and the first week of January 1961, the 12 members of the Rhode-Worthman Committee met continuously at Convair/Astronautics in San Diego and at the Air Force Ballistic Missile Division in Los Angeles. One of the objectives of this meeting was to find a majority agreement on the diagnosis for MA–1 and the prognosis for MA–2. Paul E. Purser and Robert E. Vale, representing STG, with the aid of G. L. Armstrong of Convair, argued that a "quick-fix belly band" could be effectively used to reinforce the structural strength of the "thin-skinned" Atlas. Specifically they had in mind Atlas No. 67–D, which had been at the Cape since September, being prepared for mating with capsule No. 6 for the MA–2 launch. On the other hand, Bernhard A. Hohmann of Aerospace urged strengthening the adapter ring. James A. Chamberlin forthwith had redesigned the fillets and stringers in that casing also.

Because a "thick-skinned" Atlas—one whose upper conical sections would be made of stainless steel approximately .02 instead of .01 inch in thickness, costing thereby an extra 100 pounds in weight—could not be finished and shipped to the Cape before late March 1961, the Rhode-Worthman Committee finally, but not unanimously, agreed not to wait for a replacement booster. NASA assumed the risk of a messy technical and political situation in the event of failure, and the Air Force agreed to make every effort to push MA–2 through the region of maximum aerodynamic and political stress as soon as possible. But precisely how to do this still remained debatable.[15]

New band stiffeners in the adapter ring, some 20 extra accelerometers, strain gauges, pressure sensors, and mandatory operational restrictions for mild weather, winds, and complete photographic coverage, plus the use of the improvised truss or corset, called the "belly band," for MA–2, were all included in the interim report of the Rhode-Worthman Committee, issued on January 19, 1961. The joint team effort required for these decisions, said Purser to Rhode, "admittedly has not always been easy, but we believe it has worked. 'Resolution of conflicts of technical judgment' has been achieved by mutual discussion and education rather than by manager edicts." [16] The reluctance of Aerospace and STL representatives to accept the "belly band" truss was symbolized at first by their use of the invidious metaphor "horse collar" to describe it. So apt and fitting was the "horse collar" in distributing the load of max q over the Atlas airframe that all parties accepted the nickname and the hardware by mid-February. Meanwhile work proceeded frantically in laboratories and wind tunnels at Ames and at Tullahoma, Tennessee, to provide all the information possible through simulated conditions before subjecting this "quick-fix" to a flight test. But there was great drama and suspense in the technological preparations for the vitally important launching known as Mercury-Atlas 2.[17]

Now that Vice-President Lyndon B. Johnson, an early advocate of a strong space program and slated to become the new chairman of the strengthened Space Council, promised energetic leadership among the countervailing powers in Washington, the aerospace community waited impatiently to hear who would be named the new NASA Administrator. Kennedy assigned Johnson this task of selection. Considering Johnson's long-standing interest in space matters, many observers had supposed that the selection would be made soon after the election and that the designee might be a member of the Wiesner Committee.[18] But the case was not so simple. The problem seemed to be one of settling on qualifications and then finding a man who would agree to preside over an agency with an uncertain future. The risk of becoming a political scapegoat was great indeed. The Wiesner report stipulated that one of the prerequisites for a member of the Space Council was that he be technically well-informed, and this requirement would apply also to the NASA Administrator. But whereas a university scientist with engineering and executive experience might meet this qualification, Washington and management experience also was essential.[19]

Kennedy remarked at a press conference, five days after his inauguration, that the NASA Administrator should be chosen by the end of the week, thereby deflecting newsmen's attention to the Vice-President for the name of the new Administrator. Johnson, in turn, received suggestions from his former Congressional colleagues on the space committees, and Wiesner called to Washington the man who accepted the post. On February 2, 1961, Senator Robert S. Kerr, Democrat from Oklahoma and Johnson's successor as chairman of the Senate Committee on Aeronautical and Space Sciences, presided at the confirmation hearings on the nomination of James Edwin Webb.

An experienced business head of numerous corporations, a lawyer, Director of the Bureau of the Budget from 1946 to 1949, and Under Secretary of the Department of State from 1949 to 1951, James E. Webb also had been a director of the McDonnell Aircraft Corporation and a reserve officer and pilot in the Marine Corps. Although his background was not that of a scientist, he was widely known in governmental and industrial circles for having worked with scientists on committees and with engineers as a director of such organizations as Educational Services, Incorporated; the Oak Ridge Institute of Nuclear Studies; Sperry Gyroscope Company; and as a trustee of George Washington University.[20]

Webb's appointment as NASA Administrator came as a surprise to those who expected one of the Wiesner Committee to be chosen. A few critics said that he lacked the technical background necessary to attract scientists and eminent engineers to NASA and that his nomination was a result of Senator Kerr's influence. But Wiesner supported and the Senate confirmed Webb's nomination after Webb severed all his business connections with McDonnell Aircraft. His active interest in science suggested that Webb would strive to keep a balance between science and technology in space activities. His governmental and executive experience promised that he could work well with the Bureau of the Budget and with the aerospace industries to promote NASA's interests. Webb's intellectual interests in public administration and international affairs indicated that he might become instrumental in achieving international agreements to prevent space from becoming a new theater for conflict in the cold war. Indeed, Webb's supporters felt certain that he actively would invite the Soviets to cooperate in American space exploration projects, a proposal that Kennedy had made notable in his inaugural address.[21]

With a vigorous new Administrator as its spokesman, and with the reconfirmation of Dryden as second in command, NASA quickly regained confidence regarding the scientific, budgetary, and military-industrial obstacles to its manned space flight program. In facing the military, Webb had the support of Representative Overton Brooks, chairman of the House Committee on Science and Astronautics. Early in 1961, Brooks became the first highly placed government official to lambaste the presumed campaign to build, at the expense of NASA, a stronger military space program.[22]

## MR–2: Ham Paves the Way

By the end of January 1961, the technical outlook for Project Mercury was much improved. The end of the qualification flight tests was in sight, if only the Little Joe, Redstone, and Atlas boosters would cooperate. First priority was to make sure the Mercury-Redstone combination was prepared for the first manned suborbital flights. Now, according to the progressive buildup plan, the reliability of the system required demonstration by the second Mercury-Redstone (MR–2) flight, with a chimpanzee aboard, as a final check to man-rate the capsule and launch vehicle.

Preparations for the MR–2 mission had begun long before the actual flight. Between manufacturing the capsule and flight readiness certification, several months of testing and reworking were necessary at the McDonnell plant, at Marshall Space Flight Center, and at Cape Canaveral. Capsule No. 5, designated for the MR–2 flight, had been near the end of its manufacturing phase in May 1960. When it was completed, inspectors from the Navy Bureau of Weapons stationed at St. Louis, in cooperation with STG's liaison personnel at McDonnell, watched it go through a specified series of tests, and the contractor corrected all detected deficiencies.[23] After capsule systems tests and factory acceptance tests, capsule No. 5 was loaded into an Air Force cargo plane and shipped to Marshall Space Flight Center on September 3, 1960. At Huntsville, Wernher von Braun's team hurried through its checkouts of the compatibility of capsule No. 5 with Redstone booster No. 2, and had finished well before its 16-day time limit.[24] On October 11, 1960, the capsule arrived by air at the Cape, where the first checkout inspections, under the direction of F. M. Crichton, uncovered more discrepancies, raising to 150 the total of minor rework jobs to be done. Because of the complexities of the stacked and interlaced seven miles of wiring and plumbing systems in the Mercury capsule, however, each minor discrepancy became a major cost in the time necessary for its correction. Checkout work in Hangar S required 50 days for systems tests and 60 days for rework. The capsule designated for the first manned space flight, No. 7, also had arrived at the Cape for preflight checkouts, but the launch vehicle for MR–2 was delivered to the Cape by air freight on December 20, 1960, the day after MR–1A was launched. It too had undergone exhaustive reliability testing in the shops and on the stands in the hills west of Huntsville, Alabama. When Joachim P. Kuettner, representing von Braun, transferred the MR–2 booster to Emil P. Bertram, representing Kurt H. Debus' Launch Operations Directorate, their confidence in this particular booster of the "Old Reliable" series was high but not towering.[25]

Using the "quick-look" evidence from the MR–1A flight, Marshall guidance engineers set about correcting the conditions that had made the trajectory too steep and accelerations too high. MR–1A had climbed to its programmed apogee of about 130 miles and landed 235 miles downrange, and high altitude

winds had carried it too close to the range borders. Range safety restrictions dictated that a launch vehicle must get out and away from the Cape as soon as possible. For these reasons, Walter C. Williams, STG's Associate Director for Operations, agreed with H. F. Gruene and Kuettner that the MR–2 trajectory should be flattened. An apogee of 115 miles on a downrange distance of 290 miles should be well within the allowable safety limits. Gruene and others calculated that this trajectory would still provide almost five minutes of weightless flight and a reentry deceleration of 10 g. Since this g load was slightly less than that desired by STG, Williams had to use his best persuasion during a series of consultations on the reentry loads to get Marshall to match the 12-g median reentry load by moving the engine cutoff time ahead to assure such conditions. At the same time, the range safety officer felt that the designated 105-degree launching azimuth was uncomfortably close to the shoreline. Williams, Charles W. Mathews, and Christopher C. Kraft, Jr., held out against a requested change to a 100-degree azimuth, because they wanted to minimize pilot retrieval time in case of an abort. To this STG later acceded, in exchange for its point on the 12-g reentry load; Marshall added a timer switch that would cut off the ignition if the accelerometer cutoff signal should fail before fuel depletion.[26]

Capsule No. 5 contained several significant innovations. There were five new systems or components that had not been qualified in previous flights: the environmental control system, the attitude stabilization control system, the live retrorockets, the voice communications system, and the "closed loop" abort sensing system. Capsule No. 5 also was the first in the flight series to be fitted with a pneumatic landing bag. This plasticized fabric, accordion-like device was attached to the heatshield and the lower pressure bulkhead; after reentry and before landing the heatshield and porous bag were to drop down about four feet, filling with air to help cushion the impact. Once in the water, the bag and heatshield should act as a sort of sea anchor, helping the spacecraft to remain upright in the water. Chronic problems with wave-induced fatigue of the fabric bag led STG and McDonnell engineers to concentrate on the harness linkages inside. After the Big Joe ablation flight test in September 1959, STG had decided to use on the Redstone flights, simply because they were on hand, the expensive beryllium heatshields that had first been ordered for orbital reentry. Since the anticipated reentry temperature would reach only 1000 degrees F, the beryllium shields were not necessary as heat sinks, but they served as readymade impact bumpers. Temperatures on the conical portion of the spacecraft might approach 250 to 300 degrees F, but, compared with about 1000 to 2000 degrees for an orbital mission, the ballistic flights should be cool.[27]

Publicity once again focused on the biological subject in the MR–2 experiment. The living being chosen to validate the environmental control system before committing a man to flight was a trained chimpanzee about 44 months old. Intelligent and normally docile, the chimpanzee is a primate of sufficient size and sapience to provide a reasonable facsimile of human behavior. Its average

response time to a given physical stimulus is .7 of a second, compared with man's average .5 second. Having the same organ placement and internal suspension as man, plus a long medical research background, the chimpanzee chosen to ride the Redstone and perform a lever-pulling chore throughout the mission should not only test out the life-support systems but prove that levers could be pulled during launch, weightlessness, and reentry.[28]

A colony of six chimpanzees (four female and two male), accompanied by 20 medical specialists and animal handlers from Holloman Air Force Base, where the "astrochimps" were stationed and trained, moved into quarters behind Hangar S on January 2, 1961. There the animals became acclimatized to the change from the 5000-feet altitude in New Mexico to their sea level surroundings at the Cape. Separated into two groups as a precaution against the spread of any contagion among the whole colony, the animals were led through exercises by their handlers. Mercury capsule mockups were installed in each of the compounds. In these, the animals worked daily at their psychomotor performance tasks. By the third week in January, 29 training sessions had made each of the six chimps a bored but well-fed expert at the job of lever-pulling. To condition the chimps to respond properly, they received banana pellets as rewards and mild electrical shocks as punishments.[29]

Although recovery procedures had worked well until now, recovery operations for MR–2, carrying life into space from the Cape rather than from Wallops Island, demanded extra care and attention. So STG provided the Navy with the detailed requirements, and the Navy again assigned Rear Admiral F. V. H. Hilles to command the recovery forces. Under Hilles were several task elements. One, located on the beach near the launch pad, consisted of numerous amphibious vehicles and several helicopters. Should an abort occur near the pad, these vehicles on the scene would pick up the pieces. Offshore the next recovery perimeter was covered by a small naval vessel, the *Opportune* (Auxiliary Recovery Ship 41). The largest recovery unit, the one in the anticipated landing area, consisted of six destroyers and a landing ship dock (LSD) with three helicopters on board. If the capsule were shot beyond the expected impact area, an air recovery unit consisting of four P2V aircraft from Jacksonville, Florida, would go into action.[30]

STG's man in charge of recovery operations was Robert F. Thompson, a Navy veteran who once had been first lieutenant of the deck crew aboard a destroyer and who by now had coordinated STG's recovery requirements for over two years. Through Walter Williams, Thompson asked the Navy to provide for the recovery personnel participating in the exercise and to take along photographers and public information people as well. Thompson assigned Donald C. Cheatham to brief the naval crews from Charleston, South Carolina, on postflight procedures for removing the biopack and primate from the spacecraft.[31]

According to the "Master Operational Schedule," a guidebook prepared by

Debus' experienced staff, a simulated or dress rehearsal flight must always be conducted three days before launch. For this exercise, the countdown started only 180 minutes before "launch," when Complex 56, Pad 5, the site of all the Mercury-Redstone launches, switched on the power to all systems in the Redstone. The team training of the launch crew, even for the old Redstone, required thousands of coordinated actions and easy familiarity by each of the 70 or so members of the blockhouse crew, by each of the 100 men in the Mission Control Center, and by each of another 100 people around the launch site to get a flight off the ground. While the booster was ready for mate with the capsule as scheduled in mid-January, the capsule was not ready, and the simulated flight test was carried out on January 27 for a "mission" that lasted 455 minutes.[32]

One of the procedural safeguards developed in the effort to man-rate the Redstone was the "split-count," with a built-in hold in the countdown checklist. The count began at 640 minutes before launch and stopped for a rest period 390 minutes short of liftoff time (T). At 640 minutes the complex went on critical power and the prescribed systems checks were started, the communication network readiness was verified, range equipment was checked, and the launch vehicle telemetry was tuned. At T minus 390 minutes all systems were secured for the standby period so that the crew could relax. This "split-count" became a standard part of manned preflight operations.

Before the second half of the count began, on the following day, the booster was again supplied its electrical power, the escape rocket igniter was installed but not connected, the liquid oxygen trailer truck was moved into position, weather forecast and range clearances were checked, and the booster guidance and control battery safety wires were installed. When the count was resumed at T minus 390, there were still at least 330 specific jobs to be performed or functions to be validated before liftoff.

The launch plan for the MR–2 mission followed closely all of the foregoing preparations, with each event preplanned and budgeted on the schedule. Many new systems were being qualified and, with the chimpanzee aboard, the control systems had to operate in the automatic mode. The operations directive for MR–2 specified that in case of an unduly long hold, the test would be canceled at high noon to avoid the risks of a recovery in darkness.[33]

Telemetry was to be all-important for the MR–2 mission. For that purpose two transmitters were installed in the capsule, providing eight channels of information to ground stations. These included three aeromedical channels to transmit pulse, respiration rate, and breath-depth information. The other channels carried information on structural heating, cabin temperatures, pressures, noise, and vibrations from 90 different points throughout the spacecraft.[34]

All six chimps in the colony were accorded equal treatment until the day before the flight, when James P. Henry of STG and John D. Mosely, the veterinarian from Holloman, had to choose the test subject and his substitute. First the animals were given a physical examination, and then they were each checked

on sensors, the psychomotor programmer, and consoles for comparative ratings. The competition was fierce, but one of the males was exceptionally frisky and in good humor. A female was selected as his alternate. At nineteen hours before launch these two animals were put on low-residue diets, fitted with biosensors, and checked out in their pressurized couch-cabins. Seven and one-half hours before the flight a second physical examination was given, followed by more sensor and psychomotor tests. About four hours before launch, the two chimps were suited up, placed in their couches, and brought aboard the transfer van, where their environmental control equipment was attached. The trailer truck arrived at the gantry alongside MR–2, and there, an hour and a half before the scheduled launch time, the chimpanzee named "Ham," in honor of Holloman Aerospace Medical Center, still active and spirited although encased in his biopack, boarded the elevator to meet his destiny.[35]

At sunrise on January 31, 1961, feverish preparations were underway in the community around Launch Complex 56. Walter Williams was directing operations for the third time from the newly completed Mercury Control Center. Supporting him were some 500 men from NASA, the military services, and industrial contractors. Key supervisors included the recovery force commander, range commander, launch director, capsule test coordinator, flight director, Atlantic Missile Range coordinator, network status monitor, range safety observer, and director of medical operations.[36] About 5 o'clock systems checks were progressing well, and Tecwyn Roberts, flight dynamics officer, reported that the command checks were all working "A. OK."[37] Communications checks were the same, with the exception of the Goddard link from Mercury Control on the data selection loop, and trajectory checks and displays appeared to be in order. The broken link with Goddard, discovered well before the flight, was cleared and the data selection loop restored. Although the weather was threatening and five-foot waves were reported in the recovery area, the second half of the countdown began at 7:25 a.m. After the count had progressed 20 minutes, the first trouble of the morning appeared with a report that a tiny but important electronic inverter in the capsule automatic control system was overheating. Nevertheless, at 7:53 Ham was inserted into the spacecraft, and the clear-the-pad signal horn was sounded.

A few minutes after Ham went aboard, the inverter temperature began to rise again, causing several more holds. As the wait wore on, Christopher Kraft, the flight director, sought advice about Ham's ability to endure a long hold. William S. Augerson, medical monitor in the blockhouse, assured Kraft that the animal was all right. Ham's suit temperature remained in the comfortable mid-60s, while the inverter temperature was at least three times that hot. Eventually the inverter cooled to 150 degrees F, and the count was resumed at 10:45. As soon as the power was turned on again, the inverter temperature shot up again. So another cooling-off period was called until 20 minutes before noon, when it

was decided that now or never was the time to go today. The countdown had been delayed almost four hours because of the hot inverter, but there were some other minor problems as well. The gantry elevator got stuck; too many people took too long to clear the pad area; checking the environmental control system required 20 minutes longer than planned; and the booster tail-plug cover flaps were jammed for a while.[38]

At last, five minutes before high noon on the last day of January 1961, MR–2 ignition occurred and liftoff of the Redstone followed in less than a second. As the launch vehicle rose, a transistorized television camera mounted externally near the top of the Redstone scanned the surface of the capsule and adapter ring to provide engineers with bird's-eye data on the flight behavior of the spacecraft when it blasted away from the launch vehicle. Computers sensed one minute after launch that the flight path angle was at least one degree high and rising. At two minutes, the computers predicted a 17-g load. Then, 137 seconds into the flight, the liquid oxygen supply became depleted, and in another half second the engine shut down according to the new timer-programmed plan. The closed-loop abort system on the Redstone sensed the change in engine chamber pressure upon depletion of the lox supply and fired the capsule escape system earlier than planned, within another half second. The abort properly signalled the expected Mayday message to the recovery forces, and they sped off toward a computed impact point farther downrange.[39]

The high flight angle, coupled with the early abort, added 52,000 pounds of thrust for one second, and yielded a maximum velocity of 7540 feet per second, against a planned 6465 feet. The retrorockets jettisoned prematurely when the tower aborted, which meant that the spacecraft on reentry would not be artificially slowed down and therefore would gain still more downrange mileage.[40]

An unexpected and nearly ultimate test of the chimpanzee's air circuit arose just before the abort, 2 minutes and 18 seconds into the flight, when cabin pressure dropped from 5.5 to 1 pound per square inch. This malfunction was traced later to the air inlet snorkel valve, a device that was spring-loaded to the closed position and held in place by a small detent pin. Apparently vibrations had loosened this pin and allowed the valve to open, as it was intended to do only after the main parachute opened on descent toward a water landing. Ham did not suffer, for although cabin pressure was lost, his couch pressure remained nominal, and suit temperature stayed well within the 60- to 80-degree optimum range. But the open valve caused problems after the capsule splashed.[41]

Because of overacceleration of the launch vehicle plus the added energy of the escape rocket, a speed of 5857 miles per hour was attained instead of the 4400 miles per hour planned, resulting in an apogee of 157 miles rather than the charted 115. At its zenith Ham's spacecraft was already 48 miles farther downrange than programmed, and Ham endured the weightless state for 1.7 minutes longer (6.6 minutes total) than the 4.9 minutes scheduled. He landed 422 miles

downrange after a 16.5-minute flight; the preplanned figures called for 290 miles and 14.25 minutes. His peak reentry g was 14.7, almost 3 g greater than planned.[42]

How did Ham fare through all this? The physician in the blockhouse, William Augerson, reported that at liftoff he was stable and working his levers perfectly to avoid the punishment that came from inattention. At waist level in the chimpanzee's couch was a dashboard with two lights and two levers that required two pounds of effort to depress. Ham knew well how to stay comfortable by avoiding a series of electrical shocks. Each operation of his right-hand lever, cued by a white warning light, postponed the next scheduled shock for 15 seconds. At the same time, the animal had to push the left-hand lever within five seconds after a blue light flashed, about every two minutes, in order to avoid another series of shocks to the soles of his feet.

Ham performed these tasks well, pushing the continuous avoidance (right) lever about 50 times and receiving only two shocks for bad timing. On the discrete avoidance (left) lever, his score was perfect. Reaction time on the blue-light lever averaged .82 second, compared with a preflight performance of .8 second. Ham had gone from a heavy acceleration g load on exit through six minutes of weightlessness and to another heavy g load on reentry hardly missing a trick. Onboard cameras filming Ham's reaction to weightlessness also recorded a surprising amount of dust and debris floating around inside the capsule during its zenith. The cleanliness problem still was not licked.[43]

When Ham's capsule touched down, about 12:12 p.m., no human being was in sight. Some 12 minutes later, the first electronic recovery signal from the capsule was received, and quick triangulations showed that the capsule was about 60 miles from the nearest recovery ship, the destroyer *Ellison*. Some 27 minutes after landing, Technician G. T. Beldervack, aboard a P2V search plane, sighted the capsule floating upright alone in the Atlantic. Reckoning that the *Ellison* would require at least two hours to reach that point, STG officials decided to request the Navy to dispatch its helicopters from the next closest ship, the LSD *Donner*. When the helicopters arrived on the scene, they found the spacecraft on its side, taking on water, and submerging. Wave action after impact had apparently punished the capsule and its occupant severely. The beryllium heatshield upon impact had skipped on the water and bounced against the capsule bottom, punching two holes in the titanium pressure bulkhead. The plastic fabric in the landing bag had worn badly, and the heatshield was torn free from the spacecraft before recovery. After the craft capsized, the open cabin pressure relief valve let still more sea water enter the capsule. When the helicopter pilot, First Lieutenant John R. Hellriegel, and his copilot George F. Cox, finally latched onto and picked up Ham's spacecraft at 2:52 p.m., they estimated there was about 800 pounds of sea water aboard.[44] After a dangling flight back to the *Donner*, the spacecraft was lowered to the deck and nine minutes later Ham was out. He appeared to be in good condition and readily accepted an apple and





## MR–2
## Jan. 21, 1961

*Mercury-Redstone 2, launched January 21, 1961, had the chimpanzee Ham as a passenger. At left, Ham contemplates the psychomotor test levers in his special "biopack" couch prior to the flight. At right, James Chamberlin (left) and Jerome Hammack look at the spacecraft upon its return to the Cape the following day. The landing bag (bottom) had been badly damaged and the heatshield torn free when the spacecraft was recovered by the helicopters of the U.S.S.* Donner. *Impact was probably responsible for the punctured pressure bulkhead, but the landing bag was more likely mangled by the fatigue of wave action as the capsule bobbed before pickup. This led to a great deal of last-minute redevelopment before the first manned mission.*



half an orange.[45] Ham had functioned like a normal chimpanzee in his flight into space. Could homo sapiens do as well?

Ham's flight on MR–2 was a significant accomplishment on the American route toward manned space flight. Now the Space Task Group knew that even with some hazardous malfunction it might reasonably hope to complete a manned ballistic mission successfully. Ham's survival, despite a host of harrowing mischances over which he had no control, raised the confidence of the astronauts and the capsule engineers alike. Except for an intensive effort to redesign the harness and impact attenuation system inside the landing bag, an exhausting final "quick-fix" led by Rodney G. Rose and Peter J. Armitage of STG, the Mercury capsule and all its systems seemed ready to carry man into space. Since overacceleration had occurred in both the MR–1A and MR–2 missions, however, the booster engineers responsible for "Old Reliable," Wernher von Braun and Joachim Kuettner, Kurt Debus and Emil Bertram, neither shared STG's optimism nor yet were satisfied that their launch vehicle was man-rated.[46]

## MA–2: Trussed Atlas Qualifies the Capsule

So long and anguished had been the time since July 29, 1960, when the first Mercury-Atlas combination had exploded out of sight overhead, that members of the Mercury-Atlas launch team from STG were most eager to try to fly MA–2. Laboratory and wind tunnel tests of the "belly band," or "horse collar," in late January were practically prejudged as offering no ill omens. On Inauguration Day, January 20, 1961, Robert R. Gilruth, Charles J. Donlan, Williams, Maxime A. Faget, Mathews, William M. Bland, Jr., and Purser had attended an important meeting of the STG senior staff to decide what to do about MA–2. The preliminary recommendations of the Rhode-Worthman Committee were reconsidered; after more technical talks STG decided to accept the risk and proceed with the trussed Atlas for MA–2 if top NASA management could be persuaded. While a speedup of the flight schedule leading to the orbital mission and of plans for a program to follow after Mercury's manned 18-orbit mission were being discussed at length, the STG senior staff advised NASA Headquarters that MA–2 could wait no longer.[47]

A few days later the basic mission directive document appeared in its third revised edition; in turn it was superseded by a fourth edition and by a technical information summary. At the end of January, Robert Seamans and Abe Silverstein of Headquarters accepted Gilruth's STG recommendation to fly MA–2. Before the middle of February preparations were complete. NASA had become convinced, but the Air Force was not sure MA–2 should fly yet. This was a hazardous and complex decision, shared by a number of people in Washington, at Langley, St. Louis, Los Angeles, and San Diego.[48] On February 17, Seamans called Rhode at Convair, asking his technical judgment as to MA–2's chances for success with its "belly-band fix." Rhode replied that MA–2 was structurally



## MA–2
## Feb. 21, 1961

*Mercury-Atlas 2 (right) featured the "horse collar" or "belly band," an 8-inch-wide steel corset to strengthen the interface area between this last of the thin-skinned Atlases and the adapter ring on the spacecraft. Below, McDonnell and NASA officials chat at the launch site: left to right, John Yardley, Walter Burke, and James S. McDonnell, Jr., all of McDonnell Aircraft Corporation; Wernher von Braun and Kurt Debus of NASA's Marshall Center.*



ready within acceptable wind velocities at launch.[49] George M. Low reported to the new Administrator, James Webb, that MA–2 was scheduled for launch on February 21 at 8 a.m.:

> Atlas 67–D will be the launch vehicle for this test. This is the last of the "thin-skinned" Atlases to be used in the Mercury program. It differs from the booster used in the MA–1 test in that the upper part of the Atlas has been strengthened by the addition of an 8-inch-wide stainless steel band. This band will markedly decrease the stresses of the weld located just below the adapter ring on top of the Atlas; the high stress region is shifted by about 8 inches, to a point where the allowable stresses are considerably higher. In addition to this strengthening of the top section of the Atlas, the bracing on the oxygen vent valve, which fits into the top of the Atlas tank, has been changed. The adapter between the Atlas and the capsule has also been stiffened.
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> * * *
>
> The Atlas will be cut off prematurely at a velocity of about 18,000 feet per second. The resulting trajectory will yield the most severe reentry conditions that could occur during an abort in an orbital launching.[50]

Webb and Seamans, pressed by Air Force worries over the technical, political, and public effects if MA–2 should fail, decided to trust the judgment of Rhode and Gilruth and to back NASA's commitment to accept all the blame if the worst should happen. Timely decisions by NASA had been required to permit deployment of the recovery forces to maintain the scheduled launch date.

There was so much concern over the Atlas-Mercury compatibility problem that many people almost forgot the first of several first-order objectives for the capsule and its booster. That was to test the integrity of the structure, ablation shield, and afterbody shingles of the capsule for reentry from the most critical abort situation. A second first-order objective required the Atlas abort sensing and implementation system (ASIS) to be operated "closed-loop" on the Mercury-Atlas configuration for the first time. But because MA–2 had already been made into a Federal test case, with the President, Congress, and top echelons in the Pentagon and NASA Headquarters vitally interested in its outcome, the engineers at the working levels were more anxious than ever to make this one go. Its specific results were politically less important than its general appearance of success.

The preflight checkouts had ticked off nicely the last several days before capsule No. 6 was to undergo its ordeal. And spirits were rising with the Sun on the morning of February 21, 1961. The Mercury crew for launch operations was much the same as that for MR–2, but just as Atlas was an entirely different vehicle from the Redstone, so was its military/industrial launch operations crew quite different. From the factory in San Diego had come most of the senior engineers in the Mercury booster program office, including Philip E. Culbertson, Charles S. Ames, Howard Neumann, Joseph A. Moore, and Richard W. Keehn, as well as the same machinists, welders, and test supervisors who had made the "horse collar" work in bench and tunnel tests in California. At the Cape they

worked alongside the executive agent for Mercury-Atlas launchings, the 6555th Aerospace Test Wing of the Air Force, and with Thomas O'Malley and Calvin D. Fowler, who had the industrial responsibility for actual launch operations of the Atlas. The Air Force Ballistic Missile Division representatives, Lieutenant Colonel R. H. Brundin and Major C. L. Gandy, together with Aerospace engineers Bernhard Hohmann and Ernst R. Letsch, were also on hand, watching final preparations to make this "bird" fly. Their special concern with the design and implementation of the chief reliability component of the Atlas, namely the abort system or "ASIS," also brought Charles Wilson and J. W. Schaelchlin of Convair/Astronautics, and D. R. White of Space Technology Laboratories, into the blockhouse of Launch Complex 14 on this special morning. John J. Williams was the Mercury-Atlas test conductor presiding there.

Engineers and workers at lower levels in the industrial and military hierarchy were beginning to call all these senior men "tigers" and to speak of them collectively as "tiger teams." They were the senior designers and the old-line specialists on Atlas subsystems who came out to the launch site to help the field engineers actually doing the work of final preparation for a launch.[51] Walter Williams and Christopher Kraft, in the Mercury Control Center about three miles southwest of the beach-side launch pad, watched the lights turn green one by one as the gantry backed away and "loxing" commenced about 7:30 a.m. The weather was perfect at the Cape, but 1200 miles downrange in the recovery area there were scattered squalls, which delayed the launch for one hour. Outside the Control Center that day stood Gilruth, Low, and Major General Ritland of the Air Force Ballistic Missile Division, waiting and watching for the liftoff. Each had prepared press releases in his pocket making this shot a NASA "overload" test in case of failure.

MA–2 roared off its pad at 9:12 a.m., and for the next 2 minutes the tiger teams and the managers of Mercury hardly dared breathe. An audible sigh of relief spread through the Control Center and blockhouse about one minute after liftoff, when it was announced that the "horse-collared" booster had gone through max q intact and was accelerating. At that point, said Low, "Gilruth became a young man again." Telemetry verified "BECO" and the staging of the booster engines, escape tower separation, a good trajectory, capsule separation, capsule retrofire attitude, retrorocket firing, and retropackage jettison.[52] Capsule entry attitude looked excellent at the time tracking and telemetry were lost, because of extreme range, about 9:22 a.m. Three minutes later, lookouts aboard the uprange destroyer *Greene* reported observing the reentry of both capsule No. 6 and Atlas booster No. 67–D.

> The capsule passed directly overhead and was lost in the sun at 09:37. Reentry was clearly visible and the capsule could be seen ahead of the booster tankage. The capsule was not glowing but a distinct smoke trail was seen streaming behind it. The booster tankage was glowing with an intense white glow. Several fragments appeared to be traveling along with the tankage

and tumbling at a high rate. One of the ship's observers tracked the reentry on a gun mount and indicated a separation distance between the capsule and tankage of 50 mils when it passed overhead.[53]

The landing ship dock *Donner,* almost at the center of the 20-by-40-mile elliptical dispersion area, also sighted the reentry but lost sight over the horizon northeastward before the parachute descent. Within 10 minutes, however, radio signals from the sarah beacon pinpointed the floating capsule's location, and helicopters were dispatched to pick it up after only 24 minutes in the water. It was returned to the LSD less than one hour after launch.

MA–2 was a magnificent flight, "nominal in nearly every respect." This second mission followed a flight path essentially the same as that for MA–1. The Atlas-Mercury compatibility problem had been resolved, the sequence system for the booster-capsule combination had worked perfectly, and the tracking and real-time data transmission had given immediate and excellent impact prediction from the computers at Goddard to the control centers at the Cape and on Bermuda and to the recovery forces at sea. The capsule was in extremely good condition, its ablation heatshield being charred no worse than that for Big Joe, its afterbody shingles neither burned nor warped. The Space Task Group was pleasantly surprised to find the jettisoned antenna canister and to learn, even more surprisingly, that the "mousetrap" aerodynamic destabilizing flap had not, as expected, burned away.[54]

At a press conference later that day, Gilruth beamed as he announced that this was "a very successful test" that "gives us new confidence in the integrity of the system, although I would like to caution you all that there are still a number of critical tests that have to be made before we contemplate manned orbital flight." Asked if a man could have survived this flight, Gilruth said yes. When asked whether this flight also would aid the Mercury-Redstone program, Gilruth again gave an affirmative answer, stressing the identical nature of the capsule electrical, power, abort, and parachute systems. The Earth-fixed maximum velocity of the MA–2 capsule had been approximately 12,000 miles per hour, the highest velocity achieved by a Mercury launch since *Big Joe* had demonstrated the boilerplate model of the Mercury concept. As a capstone for this happy occasion, Gilruth read a statement announcing that three out of the seven astronauts, namely "Glenn, Grissom and Shepard, in alphabetical order," had been selected to begin concentrated preparations for the initial manned Mercury space flights. The nominees had known about and been in training for their missions since January, but most Mercury engineers did not know who was assigned to which flight.[55]

## When Is a Vehicle Man-Rated?

As soon as they had recovered from their jubilant celebration after the MA–2 flight, the men responsible for Project Mercury at NASA Headquarters and in the Space Task Group looked east and west to see where they stood in the race to

put the first man into space. The Soviets had announced, on February 4 and February 12, two more unsuccessful attempts, with heavy *Sputniks IV* and *V,* to launch interplanetary space probes to Venus. These were impressive attempts by instrumented vehicles to achieve scientific firsts, but they apparently had no direct relationship to any immediate manned space flight. It had been three months since the failure of *Sputnik Cosmic Ship No. 3* on December 2, 1960. At the end of February 1961, the Soviets' open record of two failures out of three attempts with their prototype manned spacecraft made it appear that they were having as many technical difficulties as the Americans were.

During the last week in February, therefore, the international space race seemed to have cooled. At home the reliability of the Redstone was very much at issue. It was at this juncture that the von Braun and Debus Mercury-Redstone teams presented to NASA Headquarters the results of three intensive reliability studies that they had made at Marshall since the overacceleration of MR–2 had given Ham such a rough ride. The first of these three separate probability studies was based on 69 Redstone and Jupiter flight histories; the second was based on a mathematical model using a reconstruction of the flight record of all components and subsystems of the Mercury-Redstone; and the third was a still more refined reliability study using adjusted values for the human factor and system design improvements. Together these studies yielded confidence figures that "led MSFC to the opinion that the Mercury-Redstone launch vehicle reliability was in the range of 88 percent to 98 percent probability for launch success and crew survival, respectively." [56] While President Kennedy, Defense Secretary Robert S. McNamara, and Administrator Webb were learning their executive empires and were instituting a thorough review of the Nation's space program, Dryden, Seamans, Silverstein, and Gilruth accepted von Braun's insistence to postpone the first manned flight and to insert an extra Redstone booster test into the Mercury flight schedule.[57]

Whereas the Space Task Group had been elated with the performance of Ham in spite of difficulties with the capsule and the booster on the MR–2 flight the last day in January, the von Braun team at Marshall and the Cape had undergone an anguished period of reappraisal during the first two weeks in February as they tried once again to explain the "chatter" in the guidance system of their Redstone rocket. On February 6, Debus recorded in his daily journal his position with respect to the readiness status of the booster to be used for the first manned flight: "At least one unmanned shot must be obtained with flawless performance of the Mercury-Redstone mission booster flight, or at least no major shortcoming must be discovered in the vehicle system." Eberhard F. M. Rees, von Braun's Deputy Director for Research and Development, concurred and so informed von Braun. The next day Kuettner drew up an elaborate memo for internal use in deciding what should be Marshall's technical recommendation on whether to man the next Mercury-Redstone flight. In a covering note,

Kuettner explained the situation to von Braun,[58] and concluded that he personally would not advise calling a halt yet.

On Monday, February 13, 1961, Gilruth, Williams, Faget, Jerome B. Hammack, G. Merritt Preston, and Kenneth S. Kleinknecht of STG, along with John F. Yardley and R. L. Foster of McDonnell, met with the von Braun group at Huntsville to decide on "man or no man" for MR–3. By that date Debus had provided Kuettner with a list of 10 weak links, both in the hardware and in procedure, that needed correction before MR–3. The Marshall engineers incorporated their numerical guesswork into a "priority list of weak spots" that itemized seven major component problems, five minor component discrepancies, and six procedural difficulties still under study in mid-February.[59]

As Kuettner expected, political and medical considerations in the final decision to launch the first manned flight elevated the final choice to NASA Headquarters in Washington. Gilruth, his Redstone project engineer, Hammack, and the rest of STG were satisfied with the "quick fixes" made by Marshall and ground tested after MR–2. Certainly the seven astronauts felt impatiently ready to go. But von Braun and Debus reminded the Task Group of its own original ground rule for reliability: no manned flight would be undertaken until all parties responsible felt perfectly assured that everything was in readiness. Marshall engineers doubted that the difficulties encountered on the MR–1A and MR–2 missions would have endangered a human passenger. But they were committed to scrupulousness in their reliability program, too, and during the last week in February there were still seven significant modifications to the Redstone booster that seemed to require another unmanned flight test. So during this last week in February, Robert Seamans, Abe Silverstein, and Robert Gilruth acquiesced in the demands of Marshall Space Flight Center to insert one more Redstone flight into the Mercury schedule. The fateful decision was made to postpone MR–3, the first manned flight, until April 25 so something then called "MR–2A" could be inserted for a launch on March 28. On March 3 there seemed little question of the technical wisdom of this decision, although there was extreme sensitivity about the time set for the launch and about its possible public consequences.[60]

Marshall undertook to correct everything and asked STG only to provide the payload for the additional mission. Neither the Task Group nor McDonnell had an extra production capsule, so the boilerplate model that had been used on Little Joe–1B in January 1960 was refurbished and sent to Huntsville for the first mating with Redstone booster No. 5. Instead of the normal designation for the second try at an unfulfilled mission, MR–2A was renamed "MR–BD" (Mercury-Redstone Booster Development). Gilruth and company made no plans either to separate the capsule from the launch vehicle or to recover the remains. MR–BD was left primarily to von Braun and Debus, while STG turned most of its attention to Little Joe 5A. Only the operations team from STG would participate in manning the Control Center. As Marshall and the Cape made ready this flight

with the booster that had formerly been designated for the third manned suborbital training flight (MR–5), they were unaware that the Soviet Union was making ready another series of heavy Sputniks.[61]

On March 9, 1961, the U.S.S.R. announced it had launched into orbit its fourth cosmic ship, or *Korabl Sputnik IV,* weighing some 4700 kilograms (10,364 pounds) and containing a dog passenger named Chernushka. When the dog was recovered, later that day, the Soviet recovery record suddenly became two out of four tries, and NASA saw the possible consequence of its MR–BD decision. Outside of NASA, the implications were by no means clear. The newspaper space race continued unabated.

In a highly publicized letter, Representative Overton Brooks wrote to President Kennedy on March 9, 1961, of his concern over military and trade journal reports that the space program might veer toward military control. Brooks thought the Wiesner report had implied this, and he knew of a special PSAC investigating committee of scientists, called the "Hornig panel" after its chairman, Donald F. Hornig. This group, charged with an overall review of the manned space program, had just finished spending the first four days of March traveling around investigating Project Mercury. Brooks reminded the new President that the intent of the Space Act of 1958 was to ensure that control of space research remain in civilian hands so that resulting information and technological applications would be open for the benefit of all enterprise, both private and public. Too much information would become classified, he said, if the military were preeminent in space research, development, and exploration. Brooks asked for and received Kennedy's reassurance that neither he nor Wiesner had considered subordinating NASA to the military.[62]

With Kennedy's affirmation of NASA's leadership role and its 10-year plan for space research, development, and exploration, Administrator Webb concentrated on the scientific criticisms and budgetary deficiencies of the agency. Program priorities and the funds necessary for them were taken up first. Webb found that most of his staff and field scientists were enthusiastic about getting on with advanced manned space exploration beyond Mercury. They wanted large booster development and manned spacecraft and space flight development leading to exploration of the Moon. Webb also learned that the scientific community outside of NASA was not so disenchanted with manned space flight as some had supposed. Lloyd V. Berkner, a geophysicist and chairman of the Space Science Board of the National Academy of Sciences, championed the cause of NASA programs. Berkner and Hugh Odishaw had just edited an anthology, *Science in Space,* attempting to garner the support of many disciplines for an expanded space program.[63]

On March 13 and 14, Administrator Webb and his chief lieutenants began a new series of annual presentations to Congress justifying their financial requests for the coming fiscal year 1962. Abe Silverstein, spurred several times by Chair-

man Brooks of the House Committee on Science and Astronautics, departed from his prepared text on the progress of Mercury to explain the MR–BD decision in connection with the imminent first manned mission into space:

> I don't know whether you heard our briefing here several weeks ago in which we pointed out that this Redstone booster traveled 400 miles out when it should have gone 293, and went to an altitude of about 150 miles, when it should have gone to 110. These were due to some booster malfunctions. We have tracked these down and we intend to go ahead and make changes in the booster so that we have better control of it. We are not about to operate with a booster that is as sloppy in performance as that.[64]

Several days later in a speech before the American Astronautical Society, Administrator Webb publicly stated that NASA's program should be expanded to include more scientific space exploration.[65] The effort of NASA management to get White House approval at this time for post-Mercury manned flight and basic funding for booster development was to prove of historical importance.[66] On March 22, President Kennedy called Webb, Dryden, and Seamans to meet with himself, the Vice-President, and key White House staff to review the need for supplementing the NASA fiscal 1962 budget. As a result a $125.76 million increase was approved for NASA.[67] In the mind of the general public, unaware of these deliberations on an accelerated space program, NASA was thoroughly identified with Project Mercury and attention was pointing toward the first manned mission in the near future.[68]

## LJ–5A Still Premature

"The purpose of the Little Joe 5A," began the technical information summary document issued for this flight on March 6, 1961, "is to qualify the Mercury capsule, escape system, and other systems which must function during and after escape at the combination of dynamic pressure, mach number, and flight path angle that represent the most severe conditions that can be anticipated during an orbital launch on an Atlas booster." Using McDonnell's capsule No. 14, the Little Joe flight test engineers at Wallops Island were behind schedule and eager to improve on the Little Joe 5 test, which had failed on Election Day in 1960. The premature ignition of the escape rocket motor, followed by the failure of the capsule to separate from the booster, still remained unexplained. It had made the prevention of such a recurrence one of the unstated first-order test objectives of LJ–5A. Using another of the beryllium heat-sink heatshields, two Castor and four Recruit rocket motors in the booster, a special backup retrorocket system, and much better instrumentation, William Bland and his crew from STG, together with John C. Palmer, the Wallops Island range director, also hoped to get better data on the capsule's structural integrity and on its sequential, landing, and recovery systems.[69] The close simulation that Little Joe 5A should have with the Mercury-Atlas configuration was shown by the following table: [70]

| | *LJ–5A* | *Mercury-Atlas* |
|---|---|---|
| Time (sec.) | 34.4 | 60 |
| Max. q (p.s.f.) | 972 | 973 |
| Mach number | 1.52 | 1.58 |
| Flight path angle (deg) | 48.6° | 56.4° |
| Altitude (ft) | 30,960 | 34,300 |

On Saturday, March 18, 1961, after a four-hour delay caused by checkout problems, Little Joe 5A roared and soared up from the beach at Wallops Island at 11 minutes before noon. The takeoff looked good, but 20 seconds later and 14 seconds too early the capsule escape rocket again fired without the capsule. Warren North described this flight graphically:

> At 35 seconds the normal abort signal released the capsule clamp ring. A single retrorocket, which was installed as an emergency separation device, received a premature firing signal at 43 seconds. The dynamic pressure at this point was 400 psf—ten times as great as dynamic pressure at apogee where emergency capsule separation should have taken place. The capsule tumbled immediately upon separating and narrowly missed the booster as it decelerated. The retropack and escape tower were inadvertently jettisoned or torn off as the capsule tumbled. Apparently the centrifugal force and/or the escape tower removed the antenna canister, deploying both the main and reserve parachutes. The capsule descended on both parachutes which were only slightly damaged during high q deployment.[71]

Postflight analyses showed that both LJ–5 and LJ–5A had failed primarily because of structural deformations near the clamp rings that fouled the electromechanical separation systems.

The impact bag on Little Joe 5A was deployed by its barostat at 10,000 feet. The capsule drifted 10 miles on both its parachutes and finally splashed down 18 miles from the launch site, almost twice as far as planned. On top of that, the parachutes fell unreleased over the capsule as it floated in the water, thereby preventing helicopters from recovering it; a Navy salvage ship made the pickup an hour later. The capsule was in fairly good condition, with only one shingle damaged from its ordeal, and parachute loads six times higher than expected had caused no significant damage to its structure.

Spectacular but disappointing had been this test. The primary objective of qualifying a Mercury capsule during a maximum-q abort had to be rescheduled four weeks later, utilizing the last Little Joe booster. Capsule No. 14 was cleaned up, repaired where necessary, and furnished with another set of sensors, instrumentation, and telemetry for the reflight coming up, the seventh in the Little Joe series and for that reason called prematurely "LJ–7." The postlaunch report for LJ–5A summarized the reason for renaming the last Little Joe flight LJ–5B:

> Analysis of data show that the escape-rocket motor fired prematurely and prior to capsule release, thus precluding accomplishment of most of the first-order test objectives. The premature ignition was apparently caused by un-

scheduled closure of at least two of the capsule main clamp ring limit switches.

Operation of a capsule backup system by ground command separated the capsule from the booster and released the tower, making it possible for the parachutes to deploy. The main and reserve parachutes were deployed simultaneously under very severe flight conditions and enabled the capsule to make a safe landing. However, in spite of the descent rate of 60 percent less than normal, the heat shield caused some damage upon recontact. Examination of the recovered capsule showed that it did not sustain any structural damage sufficient to preclude its rapid refurbishment for another flight test.[72]

There was no time for more contingency planning if the United States hoped to orbit a man before the end of 1961. But for the moment the question in STG was not what could be done in nine months but what might be done in nine weeks.

## MR–BD Is Not MR–3

In the midst of the restudies of Mercury-Redstone reliability in early February, Wernher von Braun talked with his chief of public information, Bart J. Slattery, Jr., about the way the public had been "conditioned" to believe that the Mercury astronaut would not be allowed to ride the vehicle until 100 percent assurance of his safe return was obtained from testing. "There isn't such a thing!" proclaimed von Braun, and he added that future publicity releases should emphasize that there *"is a risk,"* perhaps greater than the traffic risks Americans take every day but possibly no greater than test pilots take with maiden flights of new jet aircraft.[73]

During the following month, while trying to reduce that risk to a minimum, the von Braun team represented by Slattery, the Space Task Group represented by John A. Powers, and NASA Headquarters represented by Paul P. Haney, agreed to plan the public information for MR–BD to avoid "over-emphasis or overly optimistic assumptions relating to future manned flights." [74]

Redstone engineers meanwhile quickly fixed the MR–BD launch vehicle, making their seven technical changes during the first two weeks in March 1961. The foremost cause of previous Redstone booster overaccelerations was a small servo control valve that had failed to regulate properly the flow of hydrogen peroxide to the steam generator, which in turn powered, and in the case of MR–1A and MR–2 overpowered, the fuel pumps. Modifications were made to the thrust regulator and velocity integrator, in hopes that MR–BD would be physically incapable of exceeding the speed limit again. Another technical difficulty had been some harmonic vibrations induced by aerodynamic stress in the topmost section of the elongated Redstone. Four stiffeners were added to the ballast section and 210 pounds of insulation was applied to the inner skin of the upper part of the instrument compartment. Although oscillations at the second bending mode frequencies were less on MR–2 than on MR–1A, several other electronic changes were made to reduce the dangers from noise and vibration.

**MR–BD**
**Mar. 24, 1961**




*The boilerplate spacecraft used on the Mercury-Redstone-Booster Development flight on March 24 is lifted by crane to its place atop the Redstone. This was an extra flight inserted into the schedule at the request of von Braun to acquire further experience with the man-rated Redstone before a manned flight was actually attempted.*

High winds aloft probably had added some extra stress in the former case, but in any event the next trajectory would smooth out the tilting maneuver in the region of high dynamic pressure, and 65 telemetry sensors were placed where the rocket's bending moments needed to be monitored. Finally, after a great deal of diagnostic study, five resettings were made to ensure that the booster engine cutoff time would not precede oxidizer depletion and hence cause another premature abort signal, as had happened with MR–2. All these changes proceeded smoothly while the boilerplate capsule was ballasted and corrugated to approximate the production model, McDonnell spacecraft No. 7, and fitted with an inert escape rocket. The capsule did not have a posi-retrorocket package.[75]

On the morning of March 24, 1961, the second half of the split countdown for MR–BD was in progress, and so far everything had proceeded without a hitch or a "glitch." To test procedures for the launch pad rescue crews, a manned M–113 armored personnel carrier was parked only 1000 feet southwest of the unmanned Redstone. The firemen in this vehicle were going to endure bone-jangling noise and vibration during the launch to see how much emergency rescue crews could stand. Closer still, an unmanned asbestos-covered truck was

parked 65 feet from the MR–BD blast deflector to simulate the position that the "cherry picker," or mobile egress tower, would occupy during the launch of a manned missile.

Liquid oxygen loading for MR–BD began only two hours before the scheduled launch time. During the automatically controlled loading process, winds of about 20 knots swayed the Redstone and produced sloshing during the "topoff" operation. The fuel temperature began to rise toward the boiling point, and soon an overflow bled out the booster standpipe and boil-off valve. This potentially dangerous situation was governed by a computer, which, when its electronic bias in the topping circuit was lowered, continued the "lox-topping" normally. No holds were called, and the countdown proceeded to launch without further incident.

At 12:30 p.m., MR–BD lifted off straight and smooth from Cape Canaveral on its programmed trajectory. The people in the armored vehicle on the ground watched it all without discomfort, and a truck driver later moved the simulated "cherry picker" away undamaged. Although the actual exit velocity was 89 feet per second higher than planned, there was in general, said Hammack in his report to STG, "hardly a plotting difference between the actual trajectory data computed . . . and the nominal trajectory published in NASA working paper 178." [76] The whole configuration impacted in the Atlantic 307 miles downrange (five miles short of the plan) and sank to the bottom, exploding a sofar bomb en route. MR–BD was highly successful; as George Low reported to Administrator Webb, it "demonstrated that all major booster problems have been eliminated." [77] Telemetry revealed that the Redstone still wriggled a bit with high vibrations in the instrument compartment, but all the "quick-fixes" had worked properly. MR–BD satisfied von Braun's team, Debus' crew, and all of NASA that the Redstone was now trustworthy enough to be called "man-rated." Enough experience was at hand to tackle the next step in Project Mercury, manned suborbital flight.[78]

But the very next day, March 25, the Soviets announced the successful launch and recovery of their fifth *Korabl Sputnik,* containing a dog named Zvesdochka, or Little Star. Three out of five was their record now for successful recovery of "cosmic ships" and dogs from orbit. Three days later, at a Soviet Academy of Science press conference in Moscow, six of Strelka's pups, as well as four other space dogs, were on exhibit as evidence and harbingers of the imminent flight of man into space. MR–BD might have been that first flight had it been "MR–3," as originally scheduled, but the decision of a month before froze the Mercury-Redstone schedule for at least two months afterward. And the Mercury team, aware of but not dominated by the space race, could only hope that the "Sputnik Spacecraft Team" was having comparable final checkout difficulties.

At the beginning of April 1961, Mercury-Redstone launch vehicle No. 7 was erected on its launch pedestal at pad No. 5 and made ready for the first mating of the man-rated capsule No. 7. Feverish activity pervaded Hangar S and the

service structure, where another "white room" was being hastily rigged on the third level of the gantry at MR–3's capsule height. Rework on the capsule's reaction control system was completed during the first week in April, while the three chosen astronauts went through final procedures training and acceleration conditioning in centrifuge runs at Johnsville. The Space Task Group now believed that the development phase of the project was practically over. Symbolizing this shift, the Associate Director responsible for development, Charles Donlan, left STG formally on the first of April to return to Langley Research Center, leaving Walter Williams, the operations chief, as Gilruth's sole Associate Director.[79]

The Space Task Group nevertheless could not afford to become too preoccupied with the preparations for MR–3 because MA–3 and Little Joe 5B were scheduled first, and within two weeks, as prerequisites for the orbital objective. On April 10, foreign correspondents in Moscow reported rampant rumors sweeping the city that the U.S.S.R. had placed a man into space. That same day at Langley Field, Virginia, another rumor reached the attention of STG to the effect that the 10 members and four consultants of the President's Hornig panel were recommending at least 50 more chimpanzee runs before putting man in space. Gilruth remarked facetiously that if this were true, the Mercury program ought to move to Africa.[80]

This hearsay recommendation did not become a part of the "Report of the Ad Hoc Mercury Panel" or of the Hornig Committee, as it was more widely known, which was submitted on April 12, 1961. Having been delegated by President Kennedy and his scientific adviser, Wiesner, the panel visited the McDonnell plant, Cape Canaveral, and Langley Field and talked with representatives of supporting services and contractors. In its 18-page report it reviewed the accomplishments and failures of the Mercury program, assessed the risks and probability of success, and commented upon medical aspects of Project Mercury as a whole and medical readiness for manned suborbital flight in particular. It concluded with some reasonable medical reservations that a Redstone flight now would be "a high risk undertaking but not higher than we are accustomed to taking in other ventures," such as in the initial flights of the Wright Brothers, Lindbergh, and the X-series of research aircraft.[81]

In its reliability assessments, the Hornig panel graded the Mercury subsystems or components according to three classes of reliability percentages: Class 1, 95–100 percent; Class 2, 85–95 percent; Class 3, 70–85 percent. Eleven items were rated as Class 1: Capsule structure and reentry properties; separation mechanism and posigrade rocket; tower and abort rockets; voice communications; abort sensing instrumentation system; manual control system; retrorocket system; parachute landing system; ground environment system; recovery operation; and pilot training. Three items were rated in Class 2: Landing bag; environmental control system; and automatic stabilization and control system. The two items in the Class 3 category, booster (Redstone or Atlas) and telemetry, were explained as "not per se a cause for alarm" for pilot safety but only for mission success.[82]

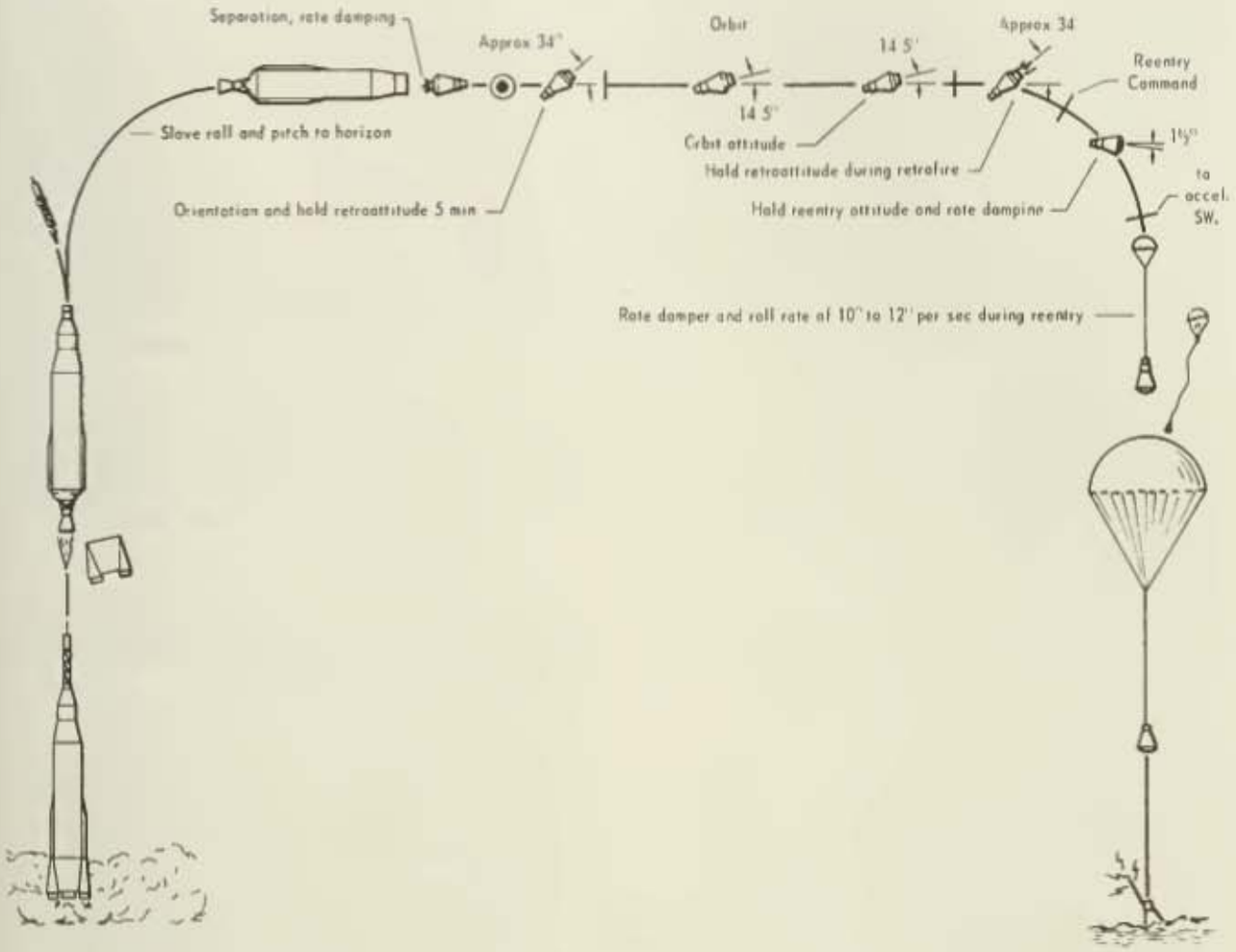
## Vostok Wins the First Lap

The first unofficial rumors out of Moscow were confirmed by an Associated Press dispatch on April 12 that translated an official Soviet news agency Tass announcement:

> The world's first space ship Vostok with a man on board, has been launched on April 12 in the Soviet Union on a round-the-earth orbit.
>
> The first space navigator is Soviet citizen pilot Maj. Yuri Alekseyevich Gagarin. Bilateral radio communication has been established and is maintained with Gagarin.

Aside from this assertion, the news out of Moscow and Turkestan on April 12 was neither crisp nor very detailed. For a few days a great deal of speculation over conflicting reports, fuzzy photographs, and the lack of eyewitnesses encouraged those disappointed Westerners who wished to believe that Gagarin's flight in *Vostok I* (meaning East) had not occurred. The danger that history might be made to order in a closed society was compounded by the rumors in the *London Daily Worker* and elsewhere since April 7. The propagandistic exploitation of this magnificent deed was evident from the fact that no confirmed announcement was made during the 108 minutes of flight—not until Yuri Gagarin landed intact near the Volga River, some 15 miles south of the city of Saratov. The present tense in the Tass dispatch above could easily have been doctored for control purposes, drama, or even for more serious reasons.[83]

Be that as it may, NASA officials from Webb and Dryden down to Gilruth and Powers, at least six months earlier, had planned their comments for this occasion, just in case. About 4 a.m., telephones began buzzing up and down the east coast of the United States as reporters demanded responses from NASA officials to the Tass dispatch. John A. "Shorty" Powers half-consciously replied to his first inquisitor, "We're all asleep down here." Some journalists ignored the fact that Gilruth had long since gone on record as saying he would not be surprised to be awakened some morning in this manner. Webb went on nationwide network television at 7:45 a.m. to extend congratulations to the Soviets, to express NASA's disappointment, and to reassure the nation that Project Mercury would not be stampeded or panicked into a premature speedup of the Mercury timetable. The next morning Webb and Dryden were roasted before the verbal fire of the House space committee as they were asked to explain what had happened. All the information available to the United States government, said Dryden, and past experience with Soviet technical statements, tended to confirm the report of Gagarin's flight. Representatives James G. Fulton of Pennsylvania, J. Edgar Chenoweth of Colorado, Victor L. Anfuso of New York, and David S. King of Utah were especially disappointed that the name Gagarin would "go down in the history books." Webb and Dryden held up well under this heat, taking the position that this particular race was lost "before the space agency was founded." But Representative Joseph E. Karth, a Democrat from




*Project Mercury normal orbital mission profile.*

Minnesota, gave the most popular rationale of why a Russian had won the first lap in the manned space race:

> The United States and the Soviet Union have proceeded along two different lines of attack. The Soviets have pretty much rifled their program, if I may use the word, as opposed to the United States shotgunning their effort. We have been interested in many programs and I think the Soviets have been interested primarily in putting a man in space.[84]

The flight of the first cosmonaut seemed remarkably similar in many respects to the plans for the first Mercury astronaut's orbital mission, but there were momentous differences as well—the single near-polar orbit, the lack of a world-wide tracking network, and the provisions for pilot ejection before impact.[85] According to the corrected and reduced data obtained from their measurements and published in *Pravda* on April 25, 1961, the twin module spaceship-satellite, or *Korabl Sputnik VI,* was renamed generically as the first in the Vostok series. Specifically its call sign was *Swallow.* The payload compartment, manned by 27-year-old, 154-pound Gagarin, weighed altogether 10,417 pounds, and attained

an apogee of 203 miles and a perigee of 112 miles, with an orbital inclination of 65 degrees to the equator. Cosmonaut Gagarin was probably launched by a two-stage booster from the Baikonur cosmodrome, east of the Aral Sea, south of the industrial district of Magnitogorsk, near Tyura Tam, a boom town comparable to Cocoa Beach, Florida. Apparently the Gagarin flight had not been preceded by a parabolic manned suborbital flight into space. The anonymous engineers behind him, mysteriously called "the chief designer" and "the chief engineer," evidently had developed a mixed-gas air supply at sea-level pressures for his life support system. *Vostok I* also had a separate and separable instrument section and retrorocket package for telemetry, television, and radio telephone communications during orbit and for braking the spacecraft velocity 5000 miles and 30 minutes before the desired impact point. Gagarin rode in a capsule almost three times the weight of the Mercury spacecraft and inside a spherical pressure vessel 7.5 feet in diameter, both of which were automatically controlled. Gagarin was the first person in history to attain an Earth-fixed speed of 17,400 miles per hour, and at this speed around his 25,000-mile course, as high as 203 miles from sea level, he was also the first man ever to endure 89 minutes of weightlessness.[86]

What the Soviets announced after the fact was indeed true:

> History's first flight in outer space, accomplished by the Soviet cosmonaut Yuri Gagarin in the space ship Vostok, has made it possible to draw the immensely important scientific conclusion that manned flights in space are practicable. It demonstrated that man can normally bear up against the conditions of a space flight, the placing of a ship in orbit, and the return to earth. This flight showed that in a state of weightlessness man fully retains his capacity for work, his coordination of movements, and his clarity of thought.[87]

And while it was hardly an overstatement to claim, as the Soviets did after the celebrations in Red Square were over, that "in the progress of science, the flight of a Soviet man in outer space pushed all other developments into the background," it must certainly have been an oversimplification that prompted Gagarin to say in retrospect: "I felt very well before the flight. I was fully confident of its successful outcome. Our machines and equipment are very reliable and I and all my comrades, the scientists, engineers and technicians, never doubted the success of the undertaking." [88]

Gagarin's flight, while not having the depressive impact of *Sputnik I* in October 1957, nonetheless came as a crushing disappointment to many Americans. The announcement was received in this country with a variety of reactions: admiration for the flight's purely scientific merits; disbelief, since various Russian accounts carried conflicting statements, at least in transliteration and at most in their technical secretiveness; and the feeling that the United States had lost face once again. The Associated Press conducted a poll in Miami, Detroit, Akron, Charlotte, Denver, Dallas, Minneapolis, Los Angeles, Oklahoma City, and Washington, D.C., by having its reporters call all the Joe Smiths in the telephone directories. The Joe Smiths registered a wide range of emotions, but perhaps

the persons feeling the keenest disappointment were the American astronauts. They knew how close and yet how far they had come toward being first in space, if not in orbit. Of the four who made statements, Glenn was most articulate and magnanimous:

> The Russian accomplishment was a great one. It was apparently very successful and I am looking forward to seeing more detailed information. I am, naturally, disappointed that we did not make the first flight to open this new era. The important goals of Project Mercury, however, remain the same—ours is peaceful exploration of space. These first flights, whether Russian or American, will go a long way in determining the direction of future endeavors. There is certainly work for all to solve the tremendous problems involved. I hope the Russians have the same objectives and that we can proceed with mutual dissemination of information so that these goals which all mankind shares can be gained rapidly, safely, and on a progressive scientific basis.[89]

## "News Will Be Worse Before It Is Better": MA–3 and LJ–5B

Although Project Mercury was not stampeded by the flight of *Vostok I,* Congress nearly was. As Mercury approached its goal, its ends became merely a means to the Moon. While the funding for Project Apollo was being discussed in Congress, the Gagarin flight provided a tremendous impetus to the desires of Americans, as mirrored in the lower house of their national legislature, to become first once again. In the chagrin of the moment, some Congressmen appeared willing to appropriate more money than NASA could spend. Robert Seamans, third in command of NASA as Associate Administrator and general manager, actually had difficulty restraining the House space committee's demands for an all-out crash program for a lunar landing. President Kennedy, consistent with one of his campaign promises, reacted to the Gagarin announcement by saying, "We are behind . . . the news will be worse before it is better, and it will be some time before we catch up." [90]

The President knew not how well he had prophesied the major Mercury events of the next two weeks. The time was up for Mercury to be first in space, but the qualification flight tests were still far from over. Mercury-Atlas 3, composed of "thick-skinned" Atlas 100–D and capsule No. 8, was, on April 10, 1961, standing on the pad at the Cape being groomed for a long ballistic flight over Bermuda and the Atlantic Ocean. A primary purpose of MA–3 was to test the dual abilities of the Cape and Bermuda to handle an abort about the time of orbital insertion. Walter Williams had already satisfied himself that this was no problem and that the MA–3 mission should be more ambitious. After Gagarin's flight the Mercury senior staff on April 14 decided it was technically feasible to change the MA–3 mission objectives to a full-scale one-orbit goal. When Warren North informed Silverstein of this change on April 17, he also noted that MA–4 should be a chimp-carrying orbital flight about mid-July.[91] However, Low,



## MA–3
## Apr. 25, 1961

*Mercury-Atlas 3 (left) was launched from the Cape April 25, 1961. Its mission was upgraded from a suborbital to an orbital attempt only a few days before the flight. MA–3 was destroyed by the range safety officer after 40 seconds of flight, the inertial guidance system having failed to pitch the vehicle over toward the horizon. The spacecraft successfully aborted and was retrieved a short distance offshore. This was the last major flight failure in Mercury.*



## LJ–5B
## Apr. 28, 1961

*Little Joe–5B (right) was launched from Wallops Island April 28, 1961. Although not nominal in flight trajectory, LJ–5B did finally demonstrate the ability of the escape and sequence systems to function properly at max-q conditions equal to the worst a Mercury-Atlas could encounter.*

acting for Silverstein, in direct consultation with Seamans, Gilruth, Williams, and others after Gagarin's flight, had already approved the speedup in the mission objectives for MA–3.

Carrying a "crewman simulator," an electronic mannequin that could "inhale" and "exhale" manlike quantities of gas, heat, and water vapor, MA–3 should test not only the capsule systems but also the reliability of this standard Mercury-Atlas. The critical tracking system and computer arrangement at Goddard, the Cape, and Bermuda must prove its ability to predict the "go/no go" decision before the danger of impacting in Africa. It was too late to change most of the documentation for MA–3, including the information summary and mission directive, but revised preflight trajectory data were hastily computed and disseminated. Computer programmers James J. Donegan of Goddard and John P. Mayer of STG worked their men through the eve of the flight checking the changed flight plan.[92]

MA–3 failed tactically, but strategically this orbital flight attempt probably did more than anything else in the Mercury program to implement the "gold-plating," or the real man-rating of the Atlas. It carried the last of the first series of capsules with the dual ports and without a landing impact bag. The capsule was to be inserted into orbit at an altitude of 100 miles and a slant range of 515 miles from Cape Canaveral. If the velocity of Atlas 100–D was not high enough, it could be aborted into any one of several preplanned recovery zones between Bermuda and the Canary Islands.

As it happened, the Atlas attempt to orbit a robot, made at 11:15 a.m. on April 25, 1961, was intentionally destroyed by the range safety officer only 40 seconds after launch when the autopilot programmer on the Atlas failed to roll and pitch the vehicle over toward the horizon. The mission having aborted, however, the entire Mercury escape system worked perfectly and the launch site recovery team responded exactly as if there had been a pilot's life at stake. The spacecraft was towed to a maximum altitude of 24,000 feet by the escape rocket and lowered gently by its main parachute a short distance offshore. The capsule came through this relatively easy abort with only minor damages and was quickly recovered and refurbished for reuse on MA–4.[93] Destroyed after its failure to initiate roll and pitch programs, booster 100–D left few artifacts as memorials of its existence. Before the official investigation board could complete its report two months later, however, a significant piece of the MA–3 autopilot, the programmer, was found buried in the mud near the beach, thereby leading to the corroboration of one of the prime hypotheses for this failure.[94]

Meanwhile, back at Wallops Island, the seventh and last booster in the Little Joe series was fitted with capsule No. 14 and made ready for a repeat of LJ–5 and LJ–5A in hopes that the third try would be charmed. This was to be an extremely critical test before MR–3. Gilruth, from Low's home in Washington, called William Bland at Wallops Island to encourage the launching if weather permitted. The preflight documentation was virtually identical to that of the previous Little Joe flight, as was the refurbished spacecraft. Still more instru-

mentation and even more careful checkout procedures to ensure that the abort would occur at the right time were instituted in addition to the redesigned clamp ring and limit switches. A steep trajectory up to about 45,000 feet was desired before tower separation and drogue chute deployment. The max-q punishment of about 990 pounds per square foot was desired to match the worst of the Atlas abort conditions.[95]

When on April 28, 1961, at 9:03 a.m., LJ–5B rammed upward, technical observers cringed when they saw immediately that one of the booster's Castor rocket motors failed to ignite for 5 seconds after liftoff. This resulted in a much lower trajectory than planned, giving a maximum altitude of only 14,600 feet, but the dynamic pressure, instead of 990 pounds per square foot, was about twice that amount, 1920 pounds. The abort was initiated about 33 seconds after launch as intended, and all events following the abort occurred as they should have. Recovery by helicopter was quick and clean, even though the low-flying capsule impacted two miles farther downrange after skidding through the atmosphere rather than vaulting through it. Lewis R. Fisher, Leo T. Chauvin, and Norman F. Smith of the STG Little Joe team were able therefore to wind up their program with a boast despite the erroneous trajectory:

> This launching successfully demonstrated the structural integrity of the Mercury capsule and escape system and sequential system under significantly more severe conditions than those expected to be encountered during a non-tumbling type of abort from an Atlas booster during a Mercury orbital launch . . . . Changes in circuitry and redesign of clamp-limit-switch installations in Capsule 14 for the Little Joe 5–B mission successfully eliminated the problem of premature ignition of the escape rocket motor.[96]

One by one the major obstacles to the growth of the manned space flight enterprise seemed to have dissolved. The opposition of some in the scientific community was not expected to become a factor in national policy. The so-called "military-industrial complex" had failed, if indeed it had ever tried, to reduce NASA. The White House and NASA administrators were determined to advance national capability in space technology. Political dangers were now neutralized. Except for the Atlas and the spacecraft's orbital capacities, all Mercury systems were qualified. Despite the embarrassment to American nationalism brought by Gagarin's flight, Mercury as a technological accomplishment was on the verge of sending a man to visit the edge of the black sea of space. And certainly this year of grace 1961 should also see an American citizen orbit the globe.[97]

## *Part Three*

# OPERATIONS

# XI

## Suborbital Flights into Space

AT 9:34 a.m. on May 5, 1961, about 45 million Americans sat tensely before their television screens and watched a slim black-and-white Redstone booster, capped with a Mercury spacecraft manned by Astronaut Alan B. Shepard, Jr., lift off its pad at Cape Canaveral and go roaring upward through blue sky toward black space.

At 2.3 seconds after launch, Shepard's voice came through clearly to Mercury Control; minutes later the millions heard the historic transmission:

> Ahh, Roger; lift-off and the clock is started . . . Yes, sir, reading you loud and clear. This is *Freedom 7*. The fuel is go; 1.2 g; cabin at 14 psi; oxygen is go . . . *Freedom 7* is still go!

America's first man in space was in flight only 15 minutes and 22 seconds and was weightless only a third of that time. *Freedom 7* rose to an altitude of 116.5 miles, attained a maximum speed of 5180 miles per hour, and landed 302 miles downrange from the Cape. Shepard experienced a peak stress of 6 g during booster acceleration and less than 12 g on reentry. Recovery operations went perfectly, the spacecraft was undamaged, and Shepard was in excellent and exuberant condition.[1]

In the light of later American space accomplishments, the flight of *Freedom 7* was impressive for its benchmark of technical excellence in the new technology of manned space flight and its hallmark of open media reporting. When compared, as it inevitably was, with the previous April 12 orbital flight of Yuri Gagarin, MR–3 was anticlimatic.

Ever since December 1958, when T. Keith Glennan, the NASA Administrator, had announced Project Mercury, the American public had awaited the first manned Mercury flight with fairly general misgivings. Many people whose expectations had been stimulated by publicity became impatient at the long delays and postponements. Some deplored the whole space program as wasteful and of doubtful value. A few still believed space travel was impossible for human beings.

Then, on February 22, 1961, the Space Task Group announced that Shepard, John H. Glenn, and Virgil I. Grissom had been chosen to begin special training for the MR–3 vault into space. More than a month before the public announcement, Robert R. Gilruth personally had made his choice, even to the exact flight order of the men selected. In early January, back at Langley, the day after he had bid outgoing Administrator Glennan goodbye in Washington, Gilruth had decided to inform the flight crewmen of their selection status. He drove over to the temporary building housing the astronaut offices, called the seven men together, and told them of his decision that Shepard would be the first flight astronaut.[2] And while the West awaited the next development, Gagarin made his 108-minute near-polar orbit of Earth aboard the five-ton *Vostok I* (meaning East) spacecraft.

Although some Americans professed disbelief in the Gagarin flight, a majority surely felt a twinge of nationalistic pain in admitting the Soviets had won the first honor in the two-nation race into space. When Shepard's flight took place, barely a month after Gagarin, even the skeptics appeared to derive consolation from the fact that the American launch and recovery had been made in the light of full publicity, with all world news media participating, whereas the Vostok flight had been veiled in official secrecy until after the fact.

*Freedom 7*, Shepard's capsule, missed what had been widely considered a "realistic" launch schedule by six months. When the capsule had finally been delivered to the Cape on December 9, 1960, some assumed the flight could be made at once. But 21 weeks of preparation—not all of it anticipated—were required by STG's Cape preflight checkout group and a host of McDonnell engineers based at the Florida site. Reaction control system checkout and rework were responsible for a launch schedule postponement to March 6, 1961. Replacement of damaged and corroded peroxide lines forced a further delay of eight days. Rerunning the simulated mission test and correcting structural and equipment defects were other time-consuming problems.[3]

Thus, technically, it was May 2 before the launch of capsule No. 7 might have been made. Then why not use capsule No. 8 or 9 or 11? Because capsule No. 7 had been selected in the summer and groomed since October 1960 as McDonnell's best product to date, the only porthole version of the capsule that had been or would be man-rated in all respects. By January 1961, after the MR–1A flight had used up Mercury-Redstone booster No. 3, the one originally intended for the first man-launch vehicle, it was clear that Redstone No. 7 would boost capsule No. 7. At the end of March, when booster No. 7 arrived at the Cape, Shepard already knew he was Robert R. Gilruth's prime choice to fly it. "There was no hope," said Shepard, "that a later model of the capsule incorporating our suggestions could be ready in time for MR–3." So capsule No. 7 on booster No. 7 should be the first combination of a series of at least seven flights to put Americans into space. "What better name or call-sign could I choose than *Freedom 7*?" asked Shepard.[4]

Although the delays were disheartening, there were compensatory benefits in the way of astronaut training. Some psychologists feared that this long time lapse before the flight actually took place might cause "over training" and staleness. But in the postflight debriefing, Shepard complimented the so-called "over training"; he remarked that the similarity of training conditions to actual flight conditions was a key factor in making the mission seem almost routine. In addition, new and better procedures were developed during repeated rehearsals of the mission, which might not have come to light had the training not been expanded a few weeks.

## Final Preparation for MR–3

The Space Task Group had decided to train Shepard, Glenn, and Grissom especially for the MR–3 mission because the competitive field had to be narrowed for this particular mission to allow the remaining astronauts to prepare for ground support jobs and the Mercury-Atlas orbital missions. Shepard's activity chart for February 1961 shows that he spent 18 days at Cape Canaveral becoming oriented to spacecraft No. 7 and its peculiarities. Long before the final phases of pilot preparations came about, Shepard and Walter C. Williams had insisted that the designated astronaut must become an integral part of the preflight checkout activities. So, based on this procedure, Shepard and Glenn acquired the special feel of No. 7's attitude control system in hangar checkouts. When the capsule was placed in the altitude test chamber, Shepard went along for the "ride" and exercised the environmental control system.

The most valuable operational training the astronaut received before his mission came from sessions in two McDonnell-built, Link-type trainers, one at Langley and the other at the Cape. These devices were first called "procedures trainers" and later "Mercury simulators." Here the space pilot, supine in a mock-up capsule, rehearsed the flight plan for a specific mission. The trainer instruments were capable of being tied in with computers at the Mercury Control Center. Overall operations team practice welded ground controllers and astronaut into a unit. Although not devoted exclusively to the MR–3 mission, the simulators were in use 55 to 60 hours a week during the three months preceding the flight of *Freedom 7*. During the entire training period, Shepard "flew" 120 simulated Mercury-Redstone flights.[5]

For an eight-week period immediately preceding the flight, the rehearsals became even more exacting. In preparing for the altitude chamber runs at space equivalent altitudes, the astronaut was examined in preflight physicals, fitted with medical sensors, including a rectal thermometer, and helped into his 20-pound pressure suit. The pilot and his medical attendants then went through the mission as realistically as conditions would allow, conducting pressure and medical checks.

Another carefully rehearsed phase of the program consisted of the transfer



*In the delay-filled weeks before the first U.S. manned spaceflight, Astronaut Alan B. Shepard, Jr., kept profitably busy with "over training," the rerunning of all phases and aspects of the flight to the point that response to them became reflexive. Left, Shepard arrives in the white room at Pad 5 on April 21, 1961, ready for the full-scale simulation of the flight. Below, he once more "flies" the mission in the procedures trainer at the Cape. Below left, he leaves the altitude chamber in Hangar S following an altitude test.*



**MR–3**
**Preflight**



of the pilot from his quarters on the balcony of Hangar S to the transfer van, the ride to the pad, and simulated flights with the astronaut sitting in the actual spacecraft. Countdowns were conducted while controllers manned their consoles. The first two rehearsal "flights," held on April 18 and 19, kept the service structure, or gantry, against the vehicle, and the capsule hatch was not closed. But the next day, on a third simulated mission, the hatch was closed, the gantry was pulled away, and the spacecraft was purged with oxygen as if an actual mission were in progress. Training like this and in the procedures trainer continued until two days before the scheduled flight.[6]

Three purposes were served by this extensive training program. The astronaut became intimately familiar with the role and voice of each person supporting the mission. He acquired more physical and mental familiarity with all of the associated hardware. And he was made even more aware of the day-to-day status leading to launch date. The operations team benefited by having the astronaut attend the team's technical briefings. These discussions covered both the spacecraft and the launch vehicle and included mission reviews held the week before launch.

On the eve of the launch, a briefing was conducted exclusively for the astronaut, with specialists in each system reporting on final readiness. Walter J. Kapryan presented the capsule and booster status; Robert B. Voas reviewed astronaut flight tasks; Christopher C. Kraft, Jr., briefed the astronaut on flight control and network status; Robert F. Thompson told him of recovery procedures; and Ernest A. Amman gave him the forecast on weather conditions. Next morning, L. Gordon Cooper, blockhouse communicator, obtained reports from key operations personnel and gave the astronaut his final ready-room briefing before he ascended the gantry. Plans for the postflight debriefing sessions, wherein the student astronaut would become the teacher of his preflight instructors, were also laid out in detail by the end of April.[7]

The planning of recovery operations was as important as any other phase of the mission. Rear Admiral F. V. H. Hilles, in command of the experienced flotilla of eight destroyers known as DesFlotFour, worked with another flag officer, G. P. Koch, aboard the carrier *Lake Champlain,* on the tactics for this mission. STG's primary strategy was to recover both man and capsule by using land-based Marine helicopters for launch-site abort situations within about 80 miles of the Cape and carrier-based helicopters in the primary recovery area, within a hundred-mile radius. Makeup of the recovery force was similar to that for MR–2, with tiered groups of men and equipment, beginning at Cape Canaveral, ready to cover all contingencies—abort, normal flight, or overflight. The main recovery force of ships was deployed in an elongated pattern 500 miles down along the range. It consisted of the carrier, eight destroyers, and one Atlantic Missile Range radar tracking ship. The helicopters again were manned by Marine Air Group 26, a veteran recovery unit.[8]

Some innovations were added to the recovery plans as a result of experience

gained in the MR–2 chimpanzee flight. For one thing, there was still the possibility that *Freedom 7* might overshoot its landing target, in which case the time factor could be vital. Obviously a highly mobile unit was desirable. Walter Williams, operations director, requested an amphibian SA–16 aircraft with a pararescue team as an emergency rescue measure. Two such teams were provided, adding the support of the Air Rescue Service and Navy frogmen to Project Mercury.

A second change involved communications. When the spacecraft was near impact it passed below the radio horizon; Williams reminded the Air Force Missile Test Center commander that continuous voice communications with the astronaut in the final moments of flight and after impact required a communications relay plane. The Air Force assigned a communications aircraft, code-named Cardfile 23, to the mission.[9]

The helicopter recovery technique was perfected late during the astronaut preparation period. According to the original helicopter recovery procedures, the chopper would lift the spacecraft with the pilot inside and ferry both to the ship. John Glenn protested that the danger in this procedure to both astronaut and helicopter pilots was too great in case trouble developed during the operation. He strongly recommended further review. After much study and practice of procedures, STG decided at a conference on April 15, 1961, to use helicopters as the primary mode of recovery. The helicopter would arrive, hover over the spacecraft, and talk with the pilot by UHF. The helicopter copilot would snip off the capsule's high-frequency antenna, snare the capsule recovery loop, and raise the vehicle slightly out of the water. By this time the astronaut would be completely out of harness and the hatch would be clear of the water. Then the astronaut would open the side hatch, crawl through, and catch a second sling lowered from the helicopter. The helicopter would hoist both astronaut and spacecraft and carry them to the main recovery ship.[10]

Since a man was to be aboard this flight, another vital part of the planning activities involved weather reporting and surveillance. Beginning in June 1960, Francis W. Reichelderfer, chief of the United States Weather Bureau, had promised to Administrator Glennan and provided for the Space Task Group full meteorological support for Project Mercury. By mid-April 1961, a special weather support group, consisting of three units under Kenneth M. Nagler, was utilizing every resource of the Bureau (including the satellite *Tiros II*) to forecast the weather accurately for STG.[11]

Before MR–3, the seven-man Miami forecast unit, headed by Jesse R. Gulick, analyzed reconnaissance data on weather conditions for 200 miles beyond the planned launch and recovery areas. Weather Bureau aircraft from Miami overflew the area at altitudes of 5000 to 20,000 feet, then, three hours before launch, dipped down below 1500 feet. The flight plan followed a box pattern, with the amount of surveillance dictated by weather conditions at a particular point. The recovery ships were integrated into a weather-reporting mission,

making reports at assigned times and providing special surface observations, such as sea state and wind velocity, at the critical time near launch. Weather observers at the launch site also kept a careful watch on air and seawater temperatures, relative humidity, cloud cover, and winds.[12]

As the flight date neared, STG personnel briefed the ship crews of the recovery force. Martin A. Byrnes, Robert Thompson, and Charles I. Tynan, Jr., of STG found the naval crews not wholly trained in the specifics of this particular mission. So they immediately initiated a brief education program, giving talks, providing reading material, and showing motion pictures of the MR–2 chimpanzee flight. Tynan also carefully briefed each man charged with capsule-handling duties on his particular role. To cradle the recovered capsule the Navy had constructed 20-by-25-foot dollies and topped them with old mattresses. Then aeromedical teams arrived, prepared sick bay areas, and briefed the ships' medical personnel. After one medical group found that two members of one of the destroyers had recently contracted hepatitis, the crew members of that ship were barred from donating blood, even in an emergency. Byrnes, who felt that the recovery-force briefings should become standard procedure for succeeding flights, said that the Navy was pleased with the pep talks.[13]

## Last-Minute Qualms

While the entire NASA program was under review by the new Administration in Washington early in 1961, Project Mercury was nearing its manned space flight phase. During the first four months of the year the major discussion would center around a proposed acceleration of the entire United States' space program to include a lunar-landing mission. Conversely, the Mercury program in the same time frame came under direct scrutiny of the President's Science Advisory Committee (PSAC), which was charged with reviewing the scientific contents of all major Federal projects. Some members of PSAC were not fully satisfied that Project Mercury was all it should be, particularly with regard to the reliability of the Redstone and Atlas boosters and to the novel life-science hazards.

The Mercury-Atlas and Mercury-Redstone failures of the year before, as was made evident in the January 1961 report of the President-elect's Space Task Force under the leadership of Jerome B. Wiesner, had not helped build the confidence of physical and life scientists that Mercury was truly a man-rated program. An ad hoc Mercury panel was created by PSAC to delve into the scientific details and reliability of the overall Mercury system and advise the President if it appeared likely that the United States would be beset with another well-publicized but inexplicable failure. Basically, the PSAC panel sought to investigate the level of risk involved in Mercury before a man was to be committed to an actual space flight. This inquiry was penetrating. Panel members spent five days in March visiting McDonnell, Space Task Group, and Cape Canaveral, receiving a series of detailed briefings and interviews. Several medical uncertainties appeared

outstanding and worrisome, although the panel had found the NASA presentations to be frank, competent, and impressive.

The scientific objective of Mercury in determining the effects of weightlessness upon man, some felt, might have been pursued in a more clinical manner. Before the first manned flight there might have been a greater number of animal flights progressing toward absolute physiological and psychological limits. Past Mercury flight tests appeared more systematic for hardware engineering than for medical problems. As a case in point, it was noted by the panel members that the MR–2 mission had demonstrated excessive vibration and overacceleration in the launch phase, so that an additional booster test flight (MR–BD) had been inserted to precede the first manned suborbital flight. Pilots in the X–15 rocket research airplane, as well as Ham, the "space chimp" aboard MR–2, had recorded surprisingly high pulse rates concurrently with low blood pressures, yet there were no plans to include a blood-pressure measuring device in the upcoming manned flight (efforts to develop such a device were as yet unsuccessful). In addition, the panel members learned that Ham had taken his turn on the centrifuge, but that the acceleration profiles had no precise correlation with stresses and forces of those predicted for the MR–2 mission.

Despite these gnawing medical doubts, in general the PSAC panel members felt that the Mercury hardware and its reliability had been developed with great care. They were especially impressed with the redundant systems of the spacecraft, as well as the procedures and devices that had been integrated to assure pilot safety during launch. In fact, several panel members stated at STG that it seemed everything necessary to assure pilot survival had been considered.

In their final analysis, the PSAC panel assessed all risks and agreed that Mercury was ready to fly a man. The scientific purpose indeed was to determine man's suitability for the stresses and weightlessness associated with space flight.[14]

The orbital flight of Yuri Gagarin on April 12 seems to have removed any lingering medical qualms about manned flight. Mercury Director Gilruth had full confidence in the Space Task Group physicians and their endorsement by the space medicine community long before *Vostok I*. W. Randolph Lovelace II, Brigadier General Don D. Flickinger, and others familiar with the medical stresses of flight likewise had been convinced that pilot safety was fully assured. Yet if the medical profession as a whole had voiced scientific opposition to manned flight in Mercury, or if *Vostok I* had not flown when it did, it would have been impossible to proceed with a man in MR–3 immediately.[15]

Centrifuge tests of the astronaut's couch continued to raise NASA confidence in the adequacy of Mercury systems to maintain an astronaut's safety under acceleration into and deceleration from the space environment. But the abrupt negative acceleration of the final impact on Earth remained a nagging worry, particularly in case of a land landing. The aluminum honeycomb shock-attenuation material under the couch had been bought as insurance, but was it enough? Continued experiments early in 1961 at Wright-Patterson Air Force Base, Ohio,

were conducted to determine how rapidly one could stop, facing aft in the semi-supine position, without exceeding human tolerance. These tests showed that forces up to 35 times a person's weight could be endured for a fraction of a second. But the volunteers so tested were momentarily stunned. In theory, this meant that a spacecraft could land without an impact bag, but the idea of having a "slightly stunned" astronaut in what should be made a routine operation was unacceptable. So STG had reassigned the development of a suitable impact bag system to Jack A. Kinzler's technical services team and to Rodney G. Rose and Peter J. Armitage. These men worked around the clock in March and April trying to perfect a seaworthy shock-absorber. All other pilot-safety systems were ready for a safe and successful flight.[16]

Barely a month had passed after the three chosen astronauts began training for MR–3 when the press began speculating as to which one would make the flight. On March 25, John Glenn became the favorite contender, although one report added that there was plenty of betting on Grissom, since the Air Force had been designated by the Defense Department to manage and conduct military space missions. This intimation of service competition spread quickly. Some newspapers even implied that the Army and Navy strongly suspected the Air Force had leaked Glenn's name to embarrass NASA and reduce his chances.[17]

The astronauts themselves watched all these conjectures with amusement, keeping tight the secret knowledge of their order of succession. According to Voas, their psychologist and training officer, there was only one thing that terrified all seven: the fear that something might prevent one of them from flying his own mission when the time came.[18]

Speculation on the designated pilot abated shortly after Robert C. Seamans, Jr., third in command at NASA Headquarters, appeared before the House Science and Astronautics Committee and testified that each astronaut would have his flight training opportunity aboard a Mercury-Redstone at six-week intervals. Gilruth had, of course, long since decided on an order of preference among the three astronauts designated, and had informed them of it, but everyone kept the secret well because of the everpresent likelihood of unforeseen changes.[19]

Toward the end of April there was so much publicity that some Senators, among them Republican John J. Williams of Delaware and Democrat J. W. Fulbright of Arkansas, thought the flight should be postponed and then conducted in secret lest it become a well-publicized failure. This was not the general view in Congress, however. Most members, while aware of the danger of too much publicity, felt tradition required the press to have free access to events of such magnitude as the first American manned space flight. Besides, the Russians had received international criticism for conducting an ultra-secret space program.

While many highly placed officials, several close to President Kennedy, were apprehensive about the possibility of an overly publicized fiasco, others pressed to get the manned space flight program moving. On March 22, at a White House meeting, Hugh L. Dryden had explained to the President that no unwar-

ranted risks would be involved in the first manned Mercury flight, and that the decision to "go" was that of the project management best qualified to assess the operational hazards. When the notion was raised in late April that MR–3 should be postponed until all possible hazards had been removed, Edward C. Welsh, Executive Secretary of the National Aeronautics and Space Council, observed to the President, "Why postpone a success?"

President Kennedy wanted to be assured of a much better than average chance for success and asked for these assurances almost until launch. On the day preceding the flight, the President's personal secretary, Evelyn Lincoln, called NASA Headquarters Public Information Officer Paul P. Haney at the MR–3 News Center in Cocoa Beach, Florida. She said the President wanted to review television coverage plans. Live coverage was to begin two minutes before launch. After some delay, Mrs. Lincoln said the President had asked Press Secretary Pierre Salinger to handle the call. Salinger said the President was concerned over the reliability of the escape system in the event of a Redstone malfunction. Haney reviewed the history of the launch escape system for the President's office and Salinger said the information should satisfy the President's inquiry.[20]

Cancellation of the flight on Tuesday, May 2, because of inclement weather, forced a recycle of the systems countdown for a 48-hour period. On Thursday unfavorable weather again prevented the launch. Countdown did begin, however, for a Friday launch.[21]

As it happened, the press and public learned the MR–3 astronaut's identity only after the countdown had been canceled, 2 hours and 20 minutes before launch, on May 2. Shepard had been waiting in Hangar S in his pressure suit ready to go for more than 3 hours. Gilruth reaffirmed his prime pilot decision a day before the scheduled launch, basing Shepard's selection on advice from his medical, training, and technical assistants.[22] But he had withheld his announcement because of the chance for a last-minute change.

The American public participated vicariously in the experiment. For the first time, the maiden flight of a revolutionary manned vehicle, climaxing years of research and development, was open wide to public view. Only a handful of spectators saw the Wright Brothers accomplish man's first powered flight in 1903. In many parts of the country and the world, people accepted that event only years afterward. But for the American taxpayers' first manned space flight, NASA arranged procedures well in advance to enable all domestic news media and foreign news services to view and report the events surrounding MR–3. By April 24, some 350 correspondents were registered. As a result of their activities, the dateline "Cape Canaveral" soon became familiar to all the world. Radio and television coverage was equally energetic; telecasts originating at the Cape, particularly on May 5, were enthralling.[23]

Starting at 8:30 p.m. on May 4, the countdown proceeded without a hitch. Around midnight a built-in hold was called for the purpose of installing the pyrotechnics, servicing the hydrogen peroxide system, and allowing the opera-

tions team some rest. The countdown was resumed in the early morning hours of May 5, and another intended hold occurred some two and a half hours before the 7 a.m. anticipated launch to assure that spacecraft checkout was complete before transporting the astronaut to the pad area.

Shepard, awakened at 1:10 a.m., began an unhurried but precise routine involving a shower and a shave. With his physician, William K. Douglas, his understudy, John Glenn, and a few other members of the operational team, he sat down to a breakfast consisting of orange juice, a filet mignon wrapped in bacon, and some scrambled eggs. Shepard had begun a low-residue diet three days before the anticipated launch. At 2:40 a.m. he received a physical examination. This was followed by the placement of biosensors at points indicated by tattoo marks on his body. He was now ready for Joe W. Schmitt, an STG suit technician, to assist him in donning the pressure suit.[24]

Shepard entered the transfer van at 3:55 a.m. In the van, on the way to the pad, he lay on a couch while technicians purged his suit with oxygen. When the van arrived at the pad, Schmitt began to attach the astronaut's gloves while Gordon Cooper briefed him on the launch status.

At 5:15 a.m. Shepard, carrying his portable air conditioner, ascended the gantry, and five minutes later he entered the spacecraft. If everything went well, he had two hours and five minutes to wait before liftoff. While Shepard was preparing to lower himself into the couch, his right foot slipped off the right elbow support. But he eased himself into position without further difficulty.

Schmitt fastened the harness and helped with the hose connections. Then he solemnly shook the spaceman's gloved hand. "Happy landings, Commander!" chorused the gantry crew.

For Alan Shepard, this was the most dramatic moment of his 37 years, a moment he would recall with the most acute poignancy for the rest of his life. Afterward he told how his heart quickened as the hatch was closed.

The sensation was brief; his heartbeat soon returned to normal. At 6:25 a.m. he began a denitrogenation procedure by breathing pure oxygen. This was to prevent aeroembolism, or decompression sickness, the airman's equivalent of the deep-sea diver's bends.[25]

Now the countdown resumed.

At 15 minutes before launch the sky became slightly overcast, so photographic conditions were below par. Weathermen said the conditions would clear in 35 to 40 minutes, and a hold was called. Shepard became resigned to this hold and relaxed by peering through the periscope. He was not uncomfortable, because he was able to shift his body in the couch. Telemetered biomedical data confirmed that his condition was good. While waiting for the clouds to clear away, a hold was called to replace a 115-volt, 400-cycle inverter in the electrical system of the launch vehicle. This hold lasted for 52 minutes, after which the count was recycled to 35 minutes before launch.

At the 15-minute point, one of the Goddard IBM 7090 computers in Maryland was found to be in error. Making this correction required a complete computer recheck-run. After a total hold time of two hours and 34 minutes, the count continued and progressed without more trouble. Shepard had been in the capsule four hours and 14 minutes when the final seconds ticked off to liftoff.[26]

Two minutes before the launch, voice communications between the astronaut and the operations team switched from Cooper in the blockhouse to Donald K. Slayton in the Mercury Control Center. From that point until launch, the "talk" was continuous as each panel monitor advised Slayton of his system's status for relay to Shepard. To the astronaut the monitors seemed slow in reporting the go condition, and this he attributed to his own eagerness to be off. Schirra was now circling above in his F–106 chase plane, waiting to follow the Redstone and Shepard as high as he could. Because of his excitement, Shepard said he failed to hear much of the closing countdown, with the exception of the firing command. During this period his pulse rate rose from 80 per minute to 126 at the liftoff signal. This rise caused no medical concern, for it was about the same as that of an automobile driver moving out from a service road to a freeway crowded with heavy traffic. Shepard was not alone in his excitement; he was joined by the operations team, the press corps at the Cape, and millions of people viewing the liftoff on television.[27]

### Shepard's Ride

Shepard saw the umbilical cable supplying prelaunch electrical power to the Mercury-Redstone and its supporting boom fall away. He raised his hand to start the elapsed-time clock that ticked off the seconds of the flight. The onboard camera, clicking at six frames per second, confirmed his alertness as the MR–3 combination roared and began to climb. He was surprised by the smoothness of the liftoff and the clearness of Slayton's voice in Mercury Control. All his transmissions were acknowledged without requests for repeat. The ride continued smoothly for about 45 seconds; then the rocket, capsule, and astronaut began vibrating. Conditioned to these circumstances, Shepard realized that he was passing through the transonic speed zone, where turbulence built up. The buffeting became rugged at the point of maximum aerodynamic pressures, about 88 seconds after liftoff; Shepard's head and helmet were bouncing so hard that he could not read his panel dials. Sound levels were noticeably higher at that point but still not uncomfortable. Shortly thereafter both the noise and the vibration abated. Now enjoying a much smoother ride, Shepard told Slayton that the dial-scanning procedure he was supposed to follow was impractical. He had to omit reading the electrical power dials to pay more attention to his oxygen and hydrogen peroxide supply indicators.

The cabin pressure inside *Freedom 7* sealed off at 5.5 pounds per square inch,

as programmed. Pressed by 6 g at two minutes after launch, Shepard still was able to report "all systems go." The Redstone's engine shut down on schedule at 142 seconds, having accelerated the astronaut to a velocity of 5134 miles per hour, close to the nominal speed. The trajectory, similar to that of the MR–BD flight, was only one degree off course, which meant a variation of slightly more than a mile in peak altitude. After engine cutoff, Shepard heard the tower-jettison rocket fire and turned his head to peer out the port, hoping that he might see the smoke from the pyrotechnics. There was no smoke, but the green tower-jettison light on his panel assured him that the pylon was gone. Shepard strained in his couch under an acceleration that hit a peak g load of 6.3. Outside the capsule the shingle temperature reached 220 degrees F, but inside the cabin the temperature was only 91 degrees. The astronaut was hardly perspiring in his pressure suit at 75 degrees.

After tower separation, which occurred two minutes and 32 seconds after launch, Shepard disarmed the retrorocket-jettison switch and advised Slayton that his capsule was free from the booster. At three minutes the automatic attitude control system about-faced the capsule to a heatshield-forward position for the remainder of the flight. Momentary oscillations climaxed the turnaround maneuver, whereupon the automatic thrusters cut in for five seconds to steady, or "damp," the capsule into its proper attitude. Now almost at the top of his suborbital trajectory, Shepard went to work on his most important task, determining whether an astronaut could control his spacecraft's attitude.

He began to switch the control system to manual, one axis at a time. First he took over pitch, which he was able to adjust by moving the handcontroller in his right grip forward or backward to give the spacecraft the proper up or down attitude. His first action was to position the spacecraft in the retrofire attitude, tilted 34 degrees above a local horizontal mark. The pitch indicator on *Freedom 7* was scribed at 45 degrees, as earlier studies had proposed, but more recent investigations had indicated that 34 degrees was a better angle.

While Shepard was in control of pitch, the automatic system was controlling yaw, or left and right motion, and roll, or revolving motions. When Shepard assumed control of all three axes, he was pleased to find that the feel was about the same as in the procedures trainer, the Mercury simulator. Although he could control his ship well, he was unable to hear the spurting control jets above the noise of his radio. He encountered one small problem while using his hand-controller: when he moved his hand to yaw, the wrist seal bearing of his suit bumped into his personal parachute. To make the proper displacement, he had to push hard.[28]

When he tried to carry out another of his flight objectives, observing the scene below him, Shepard immediately noticed that the periscope had the medium gray filter in place. While waiting on the pad, he had used this filter to eliminate the glare of the intermittently bright sunlight and had planned to remove the filter when he retracted the periscope, just before launch. But being otherwise




*Sensors are attached to Shepard by William K. Douglas*



*Launch of* Freedom 7

**Flight of *Freedom 7* May 5, 1961**



*Astronaut recovery*



*Astronaut and spacecraft safely aboard the carrier*

occupied at the time, he had forgotten to make the change. During spacecraft turnaround he tried to remove the filter, but as he reached for the filter knob the pressure gauge on his left wrist banged into the abort handle. He carefully pulled his hand away. After that he forgot about the intensity filter and observed the wondrous sights below through the gray slide. He first tried to estimate the span of his terrestrial vision. The periscope, located two feet in front of him, had two settings, low and high magnification. On low at the 100-mile altitude, there theoretically should have been a field view of about 1900 miles in diameter, and on high, a segment 80 miles in diameter. Shepard was able to distinguish clearly the continental land masses from the cloud masses. He first reported seeing the outlines of the west coast of Florida and the Gulf of Mexico. He saw Lake Okeechobee, in the central part of Florida, but could not see any city. Andros Island and the Bahamas also appeared in the scope. Later Shepard would remark that Earth displays flashed before him in his air-lubricated free-axis trainer had been most valuable in helping him to distinguish land masses passing beneath the spacecraft.

As Shepard sped over the peak of his trajectory, now under fully automatic attitude control, he began to notice a slow pitch rate. At this point his flight plan dictated that he switch to the fly-by-wire mode of operation, wherein the astronaut operated the handcontroller to change the position of the capsule, using the hydrogen peroxide jets of the automatic system to effect the changes rather than those of the manual system. Thus Shepard would manually position *Freedom 7* for the retrofire that was scheduled to occur shortly after attaining the zenith of his trajectory at 116.5 miles. The astronaut switched to fly-by-wire, but as he started to make a yaw and roll maneuver he noticed that the spacecraft pitch position was low, being 20 to 25 degrees rather than the desired 34 degrees for retrofire attitude. Although he could not remember exactly whether he made a yaw or roll maneuver, he did immediately begin to work on his pitch problem. Then the retrorockets fired, creating a noise that was easily heard but was not as loud as the sound of the ALFA trainer jets. This provided what later astronauts on orbital missions described as "a comforting kick in the pants." Pieces of debris, including a restraining strap, flashed by the capsule portholes as the retropack was jettisoned. Glancing back to the control panel, Shepard saw no confirming sequence light, but Slayton radioed his telemetered knowledge of retropack jettison. So the astronaut pushed the manual override; finally the reluctant light appeared. This was the only failure of an event-sequence light during the MR–3 mission.

While riding down the reentry curve toward a water landing, Shepard again assumed the fly-by-wire mode of control. He later reported that the feel of fly-by-wire was very similar to that of the trainers. Although he had a tendency to overcontrol in the fly-by-wire mode, he had the pleasant feeling of being in full command, for a few minutes at least, of his spacecraft's attitude. Then Shepard allowed the automatic system to regain control and stabilize the spacecraft

for reentry. The periscope automatically retracted when *Freedom 7* began its plummet into Earth's atmosphere.

On the way down, Shepard tried to look out the awkwardly placed ports to observe the stars. He saw nothing, not even the horizon. These futile attempts at star-finding got him behind in his work. As he commented later, this was the only time during the flight when he did not feel "on top" of the situation and ready for anything. The feeling of indecision passed quickly. He immediately reported when the .05-g light came on, the indication that the g-load buildup was about to commence. He was surprised that the light flashed and zero g ended about a minute ahead of the time he had come to expect from his simulated experience in the procedures trainer. As the reentry loads began to build up to a peak of 11.6 g, the oscillations also increased moderately. As soon as the highest g point had passed and the spacecraft had steadied, Shepard left fly-by-wire and cut in the automatic control system.

Shepard was supposed to give an altimeter reading between 80,000 and 90,000 feet, but since his rate of descent was faster than he expected, he became worried over the deployment of the drogue parachute and forgot to report his altitude. As the altimeter dial slipped past 40,000 feet, the astronaut braced and listened closely for the drogue mortar to fire. He gave the Cape a reading of 30,000 feet, and 9000 feet later the drogue snapped out without a kick. Once his fall was broken the periscope extended, giving a view of the trailing and reassuring drogue. The opening of the air-inlet snorkel valve to accept ambient air pressure at 15,000 feet struck Shepard as coming a trifle late. The antenna canister atop the spacecraft blew off as planned at 10,000 feet, pulling the main parachute with it. Shepard clearly saw and felt it in its initial reefed and partially unfurled condition, which prevented the lines from snapping. Within seconds it spread to its 63-foot diameter, giving the astronaut a reassuring jolt, but one considerably less violent than he had received in centrifuge simulated training. "I was delighted to see it," Shepard remarked with considerable understatement. And well he might be, for at that stage of the flight most of the critical moments had passed. *Freedom 7* had closely followed its assigned trajectory and the recovery forces were standing by for its pickup.

Falling toward the water at a rate of 35 feet per second, in contrast to the maximum rate of 6550 feet per second during the powered phase of the flight, Shepard pushed the switch to dump the remaining hydrogen peroxide fuel. Glancing at the dials, he noted another green light, indicating that the landing bag with its four-foot impact skirt had dropped down to cushion the water landing. He reported to the Cape that everything was in order before *Freedom 7* dropped below the radio horizon.

The astronaut used the brief remaining time before impact to remove his knee straps, open the faceplate shield, and remove the hose connections of his pressure suit. Then came the thud of water impact, comparable to landing an aircraft on a carrier. *Freedom 7* splashed and listed over into the water on the

astronaut's right side, about 60 degrees from an upright position. The chutes cast loose automatically on impact to prevent dragging. As the water sloshed over the ports, the spaceman saw the fluorescein dye spreading over an ever-increasing area. Shepard quickly checked the spacecraft interior to see if any leaks had resulted from impact. There were none; it was dry. Now slowly *Freedom 7* came to an upright position, taking about a minute's time, and Shepard jubilantly reported to Cardfile 23, the communications airplane, that he was all right.

Helicopters of Marine Air Force Group 26 were waiting. Wayne E. Koons and George F. Cox, pilot and copilot, respectively, of the primary helicopter, had watched the spacecraft for about five minutes on its descent. After splashdown, Koons quickly maneuvered his chopper into position for the retrieval exercise. Glancing at *Freedom 7,* Cox noted that the high-frequency antenna was not in its correct position as he hooked the cable through the recovery loop. Koons maneuvered the helicopter to lift the spacecraft partially out of the water, awaiting pilot egress. All of a sudden the high-frequency antenna pronged upward, hit and dented the bottom of the helicopter, and broke off. But no damage was done; Shepard told Koons he would debark as soon as *Freedom 7*'s hatch cleared the water.

While Shepard worked himself into a sitting posture, Koons asked again if he was ready. Not yet, he replied; he was still removing his restraint harness and he could still see water against the ports. So the chopper raised the spacecraft further and Shepard unlocked the hatch.

The astronaut then wormed his way over the hatch sill and grappled for his "horse collar" hoisting sling. He soon grasped the line and fitted the sling under his arms. On the way up he brushed against the remainder of the high-frequency antenna, but it was flexible and did no harm. The hovering chopper had no difficulty getting Shepard aboard and in lifting *Freedom 7* from the water and transporting it to the carrier *Lake Champlain.* When Shepard finally stepped on the carrier's deck, only 11 minutes had elapsed since the water landing. About half an hour after he had begun his free-dictation report, Shepard was called to the flag bridge to answer an unexpected telephone call from President Kennedy, who had watched the launching and followed flight details closely via television and who now congratulated the astronaut on his flight into space.[29]

Aboard the *Lake Champlain,* the immediate task was determining what shape Shepard was in after that brief but awesome excursion through space, with its accompanying high acceleration load, weightlessness, and deceleration loads. Some physiologists had feared that even a few minutes of weightlessness could cause disorientation, while some psychologists were equally apprehensive about what would happen to a space passenger's mind. But Shepard reported that he found his five minutes of weightlessness quite pleasant. In fact, he said, he was already in the weightless state before he realized it. For evidence, he cited a washer that had floated beside his left ear. The weightless Shepard had grabbed for the

weightless washer—and missed. Anticipating his debriefing, the astronaut had used an analogy from his professional experience to describe his sensations. The best comparison in his memory was riding in the back seat of an F–100F airplane. "It was painless," he said, "just a pleasant ride." As for any other effects of weightlessness and g stresses, Shepard had demonstrated by assuming direct pilot control that man was quite capable of functioning in space. He experienced no impairment of his faculties. He had reported to Mercury Control with perfect clarity regarding his and the spacecraft's status, and when two physicians, M. Jerome Strong and Robert Laning, made a preliminary postflight physical examination of Shepard aboard the carrier, they found him to be in excellent condition. From beginning to end the flight mission had been almost perfect. The jubilant but technically perfectionist engineers called it only an "unqualified success." [30]

Now there remained no possible doubt that man could function intelligently aboard the Mercury spacecraft and with relative safety in a true space environment for 15 minutes. What of the primitive spacecraft that he had inhabited? How well did it perform? The answer seemed to be, very well indeed. But could its systems be trusted to work under even more demanding conditions in orbital flights? Had all the flight preparations been adequate? These were only a few of the questions that the returning astronaut would have to answer, if only partially and indirectly, at the seemingly interminable debriefings.

## Briefing the Briefers

The initial postflight period of debriefing, held aboard the recovery ship, included a medical examination and free dictation by the astronaut of his flight impressions. This was followed by a short debriefing questionnaire. From the ship, the astronaut was taken to Grand Bahama Island for an exhaustive two-day debriefing by medical and technical personnel. This session used a prepared list of questions. Interrogations were led by Carmault B. Jackson on medical matters, by Robert Voas on pilot activities and performance, and by Harold I. Johnson and Sigurd A. Sjoberg on systems performance. Some 32 specialists joined in the Grand Bahama debriefing, including program managers, operations physicians, engineers, photographers, and public relations personnel.



*Astronaut Shepard arrives at Grand Bahama Island for medical and flight debriefing following his flight in* Freedom 7. *He is flanked by (left to right) Slayton, Keith Lyndell, and Grissom.*

His pressure suit, Shepard said, was generally comfortable and allowed sufficient mobility, but the left wrist pressure gauge was difficult to see during acceleration. It should be moved, perhaps to the knee. And there was a circulation problem caused by the rubber cots at the ends of his gloved fingers, which meant he had to keep drawing his fingers back inside the gloves to maintain comfort. The helmet was satisfactory. Shepard had obtained an enlarged faceplate for his own helmet to gain better vision. He had no complaints against the couch or restraint harness. He remembered only minor pressure points from the couch while waiting on the pad. The straps around his shoulders had seemed tight at times before launch, but slight shrugs had relieved the tension and stimulated circulation.

The biosensors caused some skin irritation for Shepard, as they had for others in the Mercury program, both astronauts and test subjects. Better adhesives were promised. Throughout the mission the suit temperature and humidity had been quite comfortable, Shepard reported. During the hours while he was waiting on the pad he was able to maintain a suit reading of 75 degrees, although this rose to 77 degrees a minute or two before liftoff. His suit temperature dropped back to 74.5 degrees for most of the flight, with a brief rise to 82 degrees during reentry. Just before the loss of contact as the spacecraft dropped below the radio horizon, his suit temperature dropped to 77 degrees. Then, in the capsule awaiting pickup, Shepard experienced the hottest part of the mission. When Byrnes suggested that ventilation procedures should be improved, Shepard remarked that he could have obtained some relief by simply unzipping his suit.[31]

Other parts of the environmental control system also worked satisfactorily. The cabin temperature inside *Freedom 7* stayed within a tolerable range from 92 to 100 degrees. Only part of one of the two four-pound bottles of oxygen aboard had been needed. The drain on the coolant supply had been slight.

The engineers among the debriefing team quizzed Shepard about the whole of the spacecraft attitude control systems, but especially about the workings of manual control. According to the flight plan, Shepard was to exercise three modes of control—automatic, manual, and the fly-by-wire combination of the two. He reported that the manual mode was quite responsive and felt the same as the manual mode in the procedures trainers. There seemed to be a tendency for the spacecraft to roll slightly clockwise while in the manual control. Postflight inspectors found a small piece of debris lodged in the hydrogen peroxide tubing, which probably caused the jets to leak a tiny increment of thrust. Near the six-minute point in the flight, according to plan, Shepard was supposed to switch to the fly-by-wire mode of control. Apparently he forgot to turn off the manual valve, so the capsule's attitude control system sucked fuel from both manual and automatic tanks. The debriefing interrogators asked him whether he got more control than desired; he replied that rate changes seemed high but that he thought this was caused by microswitch positions rather than the addition of manual-proportional fuel. Shepard could not recall for certain whether he had turned

off the manual valve; telemetry data monitoring the spacecraft movements and countermovements indicated that he had not.

The accessory rockets and pyrotechnics on the capsule performed adequately during the *Freedom 7* mission, each sequence firing on time and as designed. One exception was a secondary escape-tower jettison rocket, which was later disassembled and found to have ignited by manual pull-ring actuation. Since Shepard did not remember whether or not he pulled that ring, how the rocket fired remained a mystery. It was known that this backup component had not been used to separate the escape tower from the spacecraft. Otherwise the capsule rocketry had performed flawlessly. The posigrades effected spacecraft separation, the three retrograde rockets ripple-fired to provide a 510-feet-per-second velocity decrement, and the drogue parachute mortar discharged correctly. The green sequence lights appeared on Shepard's panel with heartwarming regularity except for the retropack jettison indicator.

At impact the landing bag had performed as designed to cushion the shock, but one heat sink stud did pierce the fiber-glass protective shield. While the pressure vessel was undamaged, recovery had been too rapid for the seaworthiness of the impact bag to be tested. Several rips observed in the impact skirt aboard the carrier apparently occurred during postflight handling rather than at impact or by bobbing in the water.

In general the radio communications during flight had been extremely clear. Slayton, the Mercury Control Center capsule communicator ("Cap Com"), said Shepard's voice transmissions were slightly garbled at liftoff but that seconds later the quality improved markedly. Using the ultra-high-frequency system, Slayton was able to maintain crisp contact with *Freedom 7*. Shepard and Slayton stayed on UHF, using the Cape antenna, but then as distance increased, voice communications deteriorated. In Mercury Control Center the communications technician monitoring the Grand Bahama Island antenna reception switched Slayton onto a relay from Bahama, and Shepard came in loud and clear once again. Slayton and Shepard communicated well with each other until main parachute deployment. The Mercury Control Center communicator then tried unsuccessfully to use Cardfile 23, the communications relay airplane. Having lost contact with Cap Com, Shepard had expected the recovery forces to garble the radio in competition to talk with him, but circuit discipline was businesslike both before and after countdown.[32]

### Precipitation From MR–3

The "unqualified" success of the Shepard suborbital flight brought immense joy and satisfaction to the managers, engineers, associates, and astronauts of the Space Task Group. They had labored almost two and a half years for this first triumph. Flight failures, schedule slippages, press criticism, and most recently the U.S.S.R.'s attainment of the first orbital flight, all had tempered the pride of

the Mercury team. But May 5, 1961, saw the Nation rejoice with relief and pleasure in the success and safety of Alan Shepard. President Kennedy's shore-to-ship radio telephone call to the astronaut was spontaneous, though difficult to link, and symbolic of the American mood that day. Although the seven-member corps of astronauts had combat records and test-pilot experience to their credit, one of them at last was truly a hero and not just a celebrity.

In the aftermath of the flight of *Freedom 7*, Gilruth once again published a morale memorandum for his staff. This time the subject was not a single favorable newspaper article, as had been the case of a story by Los Angeles newspaperman Marvin Miles the year before, but a compilation of formal congratulations to Alan Shepard from individuals in various walks of life, including the King of Morocco and a group of scientists in Peru.[33]

At the postflight press conference, Admiral Hilles quipped that the space race had turned into a world series played with a space ball, and that the Navy, naturally, had "caught the crucial fly." But the much more impressive Gagarin flight tempered everyone's pride but the Soviets'. What most enhanced the United States' prestige was not the technical prowess exhibited by MR–3 but the contrast between the open-door policy toward news coverage of its flight and the impenetrable secrecy surrounding the Soviet program.

One result of all this publicity was a widespread skepticism toward the space claims of the U.S.S.R. Many people around the world questioned whether a Red cosmonaut had flown at all. An Istanbul newspaper called *Millyet,* for example, reported that Turkish journalists, after viewing official films of both Shepard's and Gagarin's flights, asked of the Soviet consul general, "In the Shepard film we followed all phases of his flight, but in yours we followed only Khrushchev. Why don't you show us your space flight, too?" A Tass correspondent, replying for the consul general, was quoted as having explained, "We are mainly interested in the people's excitement and reaction. This is what we wanted you to see." [34] Premier Nikita Khrushchev was supposed to have been much chagrined because the "up and down" flight of Shepard gained such extensive media publicity even though Gagarin had long since orbited the world.

Although NASA had kept a few secrets—such as ground-control command frequencies and persisting classifications of old military data—the agency made reasonable efforts to cooperate with newsmen.



*President Kennedy presents the NASA Distinguished Service Medal to Astronaut Shepard in the White House Rose Garden. They are flanked by the other astronauts and Administrator Webb.*

The President awarded NASA's Distinguished Service Medal to Alan Shepard in a Rose Garden ceremony at the White House on May 8. Although little notice was given, crowds of people lined Pennsylvania Avenue, cheering the veteran Navy pilot and new spaceman as he rode to the Capitol for lunch and back. Here and abroad, millions of people later filed by an itinerant NASA display to inspect *Freedom 7* at close hand. Members of Congress sensed a formidable change in the public's attitude toward the space program. In place of widespread apathy or lack of understanding toward space exploration, many of their constitutents now seemed aware of the meaning of the adventures into the space void. Congressmen who had been reviewing manned space flight plans and proposals since early April began thinking about increased allocations of national resources, such as scientific manpower, for future manned space exploration.

On May 25, 1961, President Kennedy presented a special message to Congress on "urgent national needs." At one point he spoke of space and of Shepard:

> Now is the time to take longer strides—time for a great new American enterprise—time for this nation to take a clearly leading role in space achievement, which in many ways may hold the key to our future on earth.
>
> I believe we possess all the resources and talents necessary. But the facts of the matter are that we have never made the national decision or marshalled the national resources required for such leadership. We have never specified long-range goals on an urgent time schedule, or managed our resources and our time so as to insure their fulfillment.
>
> Recognizing the head start obtained by the Soviets with their large rocket engines . . . and recognizing the likelihood that they will exploit this lead for some time to come in still more impressive successes, we nevertheless are required to make new efforts on our own. For while we cannot guarantee that we shall one day be first, we can guarantee that any failure to make this effort will make us last. We take an additional risk by making it in full view of the world, but as shown by the feat of Astronaut Shepard, this very risk enhances our stature when we are successful. . . .
>
> I believe this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish.[35]

The Congress, believing that the American people were also ready to support an expanded and ambitious long-term space exploration program, quickly endorsed these words of leadership from President Kennedy. Project Apollo shifted from a circumlunar expedition plan to a lunar landing endeavor, to be achieved before 1970, or "before this decade is out."

All through March, April, and May, members of the space committees of the Senate and the House busily quizzed James E. Webb, Dryden, Seamans, and other leaders of NASA about the implications of the Russian program and about how the planned time for the development of Apollo could be cut in half. But the appropriations debate was brief. By August 7, the Senators and Repre-

sentatives had agreed on $1,671,750,000 for NASA's fiscal 1962 budget. This was the first time Congress had appropriated over a billion dollars for NASA's space program at one time. Only $113 million less than President Kennedy had requested, this billion and a half dollars was but an initial appropriation, for the legislators understood that NASA would ask for a supplement about January 1962.[36]

Thus American aspirations in space, personalized by Astronaut Shepard on May 5 and codified by President Kennedy's endorsement of NASA's follow-on plans on May 25, 1961, gained clear direction, ample funds, and official sanction. The national mood for space had definitely changed from what it had been at the uncertain beginning of the Kennedy administration. A goal of developing space technology for space exploration was a tangible means to "get the country moving again."

Industries born of the frantic missile race of the mid-fifties would turn more and more to space-related research and development. Unlike military technology, such products were not needed in quantity; reliable performance was their highest criterion. Whereas Project Mercury, toward the end of its manufacturing phase in June 1961, supposedly affected approximately one out of 90 people in the United States through industrial support of some 10,000 companies, Project Apollo as redefined by NASA and approved by the President would take far more of a national effort.[37] Kennedy had promised that expanded conquest of space would be difficult and costly. But so impressive and dramatic an enterprise was Apollo, so full of engineering and gadgetry, that the project seemed made to order for a new American destiny. To President Kennedy, the United States could win an open competition with the Soviet Union in space because of the inherent superiority of an open society.

Besides its portents, the President's decision had an immediate impact on the Space Task Group, an organization that had been studying the possibilities of advanced manned flight as early as 1959. In September 1960, the Apollo projects office formally appeared on the organization chart of the Space Task Group's Flight Systems Division, indicating the fulltime status of planners for Apollo. But the day after President Kennedy's speech of May 25, Wesley L. Hjornevik, formerly Glennan's administrative assistant and now Gilruth's, signed a notice to the Space Task Group that reassured the Mercury team of a future with Apollo. New funds and facilities, if approved by Congress as expected, would certainly affect the personal lives of the Space Task Group members by the necessity to reorganize and perhaps to relocate.[38]

NASA Headquarters had recognized for some time that a center was needed to survey the whole spectrum of manned space flight programs. On January 3, 1961, the Space Task Group had at last been designated an autonomous field element, no longer to be considered a part of the Goddard Space Flight Center. The Space Task Group's personnel strength had increased to a total of 794 people in mid-1961. Until Kennedy's lunar landing decision was en-

dorsed by the Congress, the Space Task Group had had only one responsibility, Project Mercury, and no authorization to proceed with more ambitious endeavors. The end of Project Mercury could have meant the end of the Space Task Group.

But President Kennedy's clarion message to Congress verified a new course for the Space Task Group's civil servants. Back in February 1961, Gilruth had asked his second in command, Charles J. Donlan, to begin considering the most feasible programs to succeed Project Mercury. Whatever the future programs were, they would require new, separate, functional facilities. By May a draft study was completed on how such undertakings should be managed. Entitled "Organizational Concepts and Staffing Requirements" for a "Manned Spacecraft Development Center," the study declared in its preamble:

> One of the essential elements required to implement an agressive national effort for manned space exploration is a capability within government to conceive, manage, and technically monitor the development of large manned spacecraft and to operate the spacecraft and related ground support equipment. This portion of the total job is in itself one of the largest, if not the largest research and development job ever undertaken in war or peace.
>
> The nucleus of the capability now exists in the Space Task Group, which has handled, with industry and other government resources, the Mercury Program. However, a program of the much larger magnitude now contemplated would require a substantial expansion of staff and facilities and instituting an organizational and management concept consistent with the magnitude of the program. How—and how effective—the capability is organized will have a direct bearing on the success or failure of the total program.[39]

Only a few days had elapsed after President Kennedy's call to Congress for approval of the lunar landing program when the rank and file members of the Space Task Group began to read speculations in their local Virginia newspapers about where they might have to move. Few were eager to leave the Virginia peninsula. Many were glad to stop worrying about a move to Beltsville, Maryland, but no one knew what the alternative site would be. While wives and families fretted, the men and women of the Space Task Group were busier than ever before, because the group had just entered the final manned phase of the Mercury program. In August 1961, NASA Headquarters ordered John F. Parsons, Associate Director of the Ames Research Center, to head a survey team to recommend the permanent location for a manned spacecraft center. One of the members of the Parsons team, Martin Byrnes, was subsequently assigned to study relocation programs for STG's members.[40]

Responsibilities lay heavily upon STG. It had to accelerate the Mercury program to achieve its primary objective, manned orbital flight. It should start to recruit personnel and organize activities for the newly authorized Project Apollo. And, most immediately, it must carry out the second suborbital Mercury flight as scheduled. Once the next astronaut was recovered, the operations team in concert with the Space Task Group management would have to decide just how far to carry the Mercury-Redstone suborbital program. Many of the 30 or so

who had attended Shepard's postflight debriefing felt that this phase had served its purpose and that now the manned orbital phase should be initiated. This point was discussed in June but not by any means decided. From Shepard's success, however, one thing seemed clear: it was certainly not necessary to train all the astronauts on suborbital flights before trying to duplicate or triplicate Gagarin's feat.

### Second Suborbital Trial

Preparation for the second suborbital flight of man into space was essentially the same as that for Shepard and *Freedom 7*. Much of the astronaut and ground support training, spacecraft checkout, and booster preparation had been accomplished concurrently with the grooming of MR–3, since the anticipated six-week interval was too short to begin anew. Thus Air Force Captain Virgil I. Grissom, told by Gilruth in January 1961 that he would probably be the pilot for Mercury-Redstone 4, and John H. Glenn, Jr., once again the suborbital backup pilot, returned to work quickly after Shepard's flight. In April all three had undergone refresher centrifuge training at Johnsville, and now they were well fortified to endure the actual Redstone acceleration profile.

Most of their training period was spent at the Cape so that Grissom and Glenn could follow the technical progress of spacecraft and launch vehicle by participating in minute checkout operations. In Hangar S the astronauts exercised themselves and all their capsule systems in the simulated high-altitude chamber tests. Their physicians recorded metabolic data and refined physiological reactions. Communication checks, manual control system checks, sequence system verifications, and many simulated missions in the procedures trainer kept them busy. Twice Grissom and Glenn went back to Langley for sessions in the ALFA trainer. In all, each simulated about 100 Mercury-Redstone flights before the upcoming MR–4 launch, scheduled for July.[41]

Spacecraft No. 11, designated since October for the second manned Mercury flight, had come off the production line at McDonnell in May 1960. As the first operational capsule with a centerline window, No. 11 more nearly approximated the orbital version of the Mercury capsule than Shepard's *Freedom 7*, or spacecraft No. 7.[42]

Among other innovations in No. 11 for MR–4 was an explosive side hatch, whose evolution, encouraged by the astronaut corps, had begun early in the Mercury program. The original egress procedure had been to climb out through the antenna compartment, a difficult maneuver that required the removal of a small pressure bulkhead. Since all the astronauts had found it hard to snake out the top of the frustum and cylinder, the STG and McDonnell designers had concluded that removal of an injured astronaut would be even more precarious. Moreover, valuable time would be lost in such a rescue






*At left, Grissom in spacecraft check. At right, Grissom (seated inside) tests spacecraft on the gantry with Guenter Wendt of McDonnell Aircraft Corporation.*

## MR–4
## Preflight

*MR–4 Mission Review Conference at the Cape: left to right, Slayton, Grissom, Kenneth M. Nagler, Warren J. North, William K. Douglas, Glenn, Shepard, Charles W. Mathews, John D. Hodge, Stanley C. White, and Christopher C. Kraft, Jr.*



operation; to open the hatch from the outside, someone had to remove several shingles and 70 bolts.

McDonnell engineers set to work on the problem and came up with two egress hatch models—one with a latch, which was used on Ham's MR–2 and Shepard's MR–3 missions, the other with an explosive hatch cover. The simple latch mechanism weighed 69 pounds, too much of a weight addition for incorporation in the orbital version of the spacecraft. The explosive hatch, on the other hand, utilized the 70 bolts of the original design; a .06-inch hole was bored into each of the quarter-inch titanium bolts to provide a weak point. When a mild detonating fuse, placed in a groove around each bolt, was energized, the bolts were sheared simultaneously and the hatch sprang open.

There were two ways to activate the explosive egress hatch during recovery. About six to eight inches from the astronaut's right arm, as he lay in his couch, was a knobbed plunger. The pilot would remove a pin and press the plunger with a fist-force of five or six pounds, detonating the small explosive charge and blasting the hatch 25 feet away in a second. If the pin was in place, a fist-force of 40 pounds was required. A rescuer outside the capsule could blow open the hatch simply by removing a small panel from the fuselage side and pulling a lanyard. This complete explosive hatch weighed only 23 pounds.[43]

The welcome new trapezoidal window assembly on spacecraft No. 11 replaced the two 10-inch side ports through which Shepard strained to see. The pilot now could look upward slightly and see directly outside. Visually the field covered 30 degrees in the horizontal plane and 33 degrees in the vertical. The Corning Glass Works of Corning, New York, designed and developed the multilayered panes. The outer pane was made of Vycor glass, .35-inch thick, and could withstand temperatures on the order of 1500 to 1800 degrees F. Three panels were bonded to make the inner pane, one a .17-inch-thick sheet of Vycor, the two others made of tempered glass. This fenestration was as strong as any part of the capsule pressure vessel.[44]

The manual controls for the second manned flight incorporated the new rate stabilization control system. With it the astronaut could control the rate of spacecraft attitude movements by small turns of his hand controller rather than by jockeying the device to attain the desired position. This rate damping or rate augmentation system, like power steering on an automobile, gave finer and easier handling qualities and another redundant means of driving the pitch, yaw, and roll thrusters.

By the time of the MR–4 flight, Lewis Research Center and Space Task Group engineers had analyzed the thrust rating of the posigrade rockets and had made a valuable discovery. Fired into the booster-spacecraft adapter, the posigrade rockets developed 78 percent greater thrust than when fired openly. Accordingly the capsule separation rockets when ignited inside the adapter, producing what the NASA testers called a "popgun effect," afforded an initial

separation velocity of about 28.1 feet per second. This determination provided the engineers with the confidence that spacecraft-booster separation would occur with little likelihood of recontact.

STG's calculations indicated that the Redstone booster and the Mercury spacecraft should be about 4000 feet apart on their suborbital trajectory at retrofire. The unbraked booster would hit the water some 566.2 seconds after launch, while the longer and steeper trajectory of the spacecraft would keep it aloft 911.1 seconds. The booster would land about 16½ miles beyond the spacecraft.[45] Because of the relatively short distance between the two impact points, STG was concerned enough to assign John P. Mayer and Ted H. Skopinski to study the problem, especially as related to possible recontact of the spacecraft and the booster after separation. As a result of the studies, Skopinski's recommendations for minor changes in the sequencing of retrofire were accepted as solutions to prevent recontact.

Other hardware changes involved attaching a redesigned fairing for the capsule adapter clamp-ring, rearranging the capsule instrument panel, and adding more foam padding to the head area of the contour couch. The fairing and some more insulation should overcome the vibration and consequent blurred vision Shepard had complained about, while the rearrangement of the instruments sought to improve the eye-scan pattern, which Shepard had found poor. These changes cost several more weeks' time. On July 15, 1961, Gilruth affirmed that Grissom would be the prime pilot for Mercury-Redstone No. 4 and that Glenn would be his stand-in. Grissom in turn announced that he had chosen the name *Liberty Bell 7* as the most appropriate call-sign for his bell-shaped capsule, because the name was to Americans almost synonymous with "freedom" and symbolic numerically of the continuous teamwork it represented.[46]

Modifications made on Grissom's pressure suit reflected the experiences of Shepard's flight. Nylon-sealed ball-bearing rings were fitted at the glove connections to allow full rotation of the wrists while the suit was pressurized. A new personal parachute harness was designed to keep the chute out of the way. On the chest of Grissom's suit was a convex mirror, called a "hero's medal" by the astronaut corps, that served simply to allow the pilot-observer camera to photograph instrument readings. Another welcome addition to the suit was a urine reservoir, fabricated the day before the flight. Although during his flight Grissom would find the contraption somewhat binding, it did work. Lastly, Grissom's helmet was equipped with new microphones that promised to filter out more noise and make transmission quality even better.[47]

Materials successfully used in other phases of the space program also became a part of the second manned flight. In the continuing quest for weight reduction, a lightweight, radar-reflective life raft was developed jointly by the Langley Research Center and the Space Task Group. Weighing three pounds and four ounces (45 percent lighter than the original version), this raft was constructed

of Mylar and nylon, the same materials used in *Echo I*, the passive communication satellite balloon that began circling the globe in August 1960. The survival pack, with the raft inside, was secured on a shelf in the spacecraft conveniently near the astronaut's left arm.[48]

Grissom's flight plan was revised rapidly and altered substantially as a result of MR–3. Shepard had really been overloaded with activities during his five minutes of weightlessness. Now Grissom was given a chance to look through his new trapezoidal window to learn more about man's visual abilities in space. If he could recognize landmarks for flight reference, the pilot tasks for the Mercury orbital flights might be considerably simplified. Shepard had assumed manual control of only one axis of movement—yaw, pitch, or roll—at a time, whereas Grissom had instructions to assume complete manual control as soon as he could, to make three maneuvers in about one minute instead of Shepard's 12 minutes, and then to spend as much time as possible making exterior observations.

Mercury-Redstone booster No. 8 had arrived at Cape Canaveral on June 8. Kurt H. Debus' contingent of Wernher von Braun's team and G. Merritt Preston's capsule checkout team had proceeded with the mating of the launch vehicle and capsule and the checkout requirements. On July 13, the flight safety review was held and the spacecraft was pronounced ready for flight. Two days later Walter Williams heard the reports during the mission review; the Redstone and *Liberty Bell 7* were pronounced ready to go. The recovery ships, anticipating the launch date on Tuesday, July 18, moved into their assigned positions.

Essentially a repeat of MR–3, Grissom's flight was to reach an apogee of 116 miles, over a range of 299 miles, with the astronaut feeling a maximum acceleration load of 6.33 g and deceleration of 10.96 g. Only the launching azimuth, changed by three degrees to stay within range bounds, varied from Shepard's flight into space.[49]

On July 16 the news media received a weather bulletin predicting that the cloud cover in the launch area for the next 48 hours would be below average, but that the impact area would be slightly cloudier than usual. The mission was postponed early Tuesday, the 18th, in hope of better weather. Fortunately the frosty liquid oxygen had not been loaded so the launch delay was only 24, rather than 48, hours.

Early Wednesday, July 19, Grissom, asleep in his quarters on the balcony of Hangar S, was awakened by his physician, William Douglas, who told him that Walter Williams' operations team was pushing for a 7 a.m. launch to beat the weather. The launch day routine began again. By 5 a.m. Grissom was up in the gantry. He slid into his niche; the count resumed and continued unbroken until 10 minutes and 30 seconds before launch, when a hold was called to wait for a rift in the cloud cover. When no break appeared, the mission was scrubbed again. This time the liquid oxygen had been tanked, so a dreary 48-hour delay would be necessary.[50]

The weather conditions on July 21 were still not ideal. The view from an

altitude of a hundred miles would show that all the northern portion of Florida was completely obscured by high cirrus and lower patches of cumulus clouds. Southern Florida and Cuba would be splotched by scattered cumulus. The operations team nevertheless decided that since the view was not essential to the success of the mission, the launch should come off as scheduled.[51]

Because Grissom had shaved and showered before going to bed rather than before his low-residue breakfast, and because Slayton, the blockhouse communicator, briefed the astronaut on the status of the capsule and booster during the van ride to the pad rather than just before gantry ascent, the routine was a bit less hurried. George E. Ruff, an Air Force psychiatrist, had time to interrogate Grissom about his feelings before he lay in his contour couch for MR–4's liftoff.[52]

Grissom was unruffled, calm, and poised as he entered *Liberty Bell 7* again. The count resumed and proceeded smoothly until 45 minutes before launch time, when a gantry technician discovered that one of the 70 hatch bolts was misaligned. A 30-minute hold was called, during which the McDonnell and STG supervisory engineers decided that the remaining 69 bolts were sufficient to hold and blow the hatch, so the misaligned bolt was not replaced. The countdown was resumed, but two more holds for minor reasons cost another hour's wait.[53]

Alone in his capsule awaiting liftoff, Grissom experienced a wide range of impressions. As the gantry, or service structure, moved back from the launch vehicle, he had the illusion that he was falling. His pulse rate ranged from 64 to 162 beats per minute, depending upon his feelings. His heart beat rose during the oxygen purge, fell while the hatch bolt repair decision was being made, rose again when the go decision was made, and finally doubled at launch. His liftoff was at 7:20 a.m.[54]

## Liberty Bell Tolls

Grissom later admitted at the postflight debriefing that he was "a bit scared" at liftoff, but he added that he soon gained confidence along with the g buildup. Hearing the engine roar at the pedestal, he thought that his elapsed-time clock had started late. Like Shepard, he was amazed at the smooth quality of the liftoff, but then he noticed gradually more severe vibrations, never violent enough to impair his vision. To the watchers on the ground, the Redstone and the capsule appeared to rise slowly and to pass through a thin, broken cloud window. Then the rocket disappeared, leaving a contrail that was visible on the beach for about a minute. Grissom's cabin pressure sealed off at the proper altitude, about 27,000 feet, and he felt elated that the environmental control system was in good working order. The suit and cabin temperature, about 57.5 and 97 degrees F, respectively, were quite comfortable. Watching his instruments for the pitch rate of the Redstone, Grissom saw it follow directions as programmed, tilting over about one degree per second.

Under a 3-g load on the up-leg of his flight, Grissom noticed a sudden change in the color of the horizon from light blue to jet black. His attention was distracted by the noise of the tower-jettison rocket firing on schedule. The pilot felt the separation and watched the tower through the window as it drifted off, trailing smoke, to his right. At two minutes and 22 seconds after launch, the Redstone's Rocketdyne engine cut off after building a velocity of 6561 feet per second. Grissom had a strong sensation of tumbling during the transition from high to zero g, and, while he had become familiar with this sensation in centrifuge training, for a moment he lost his bearings.

The Redstone coasted for 10 seconds after its engine cut off; then a sharp report signaled that the posigrade rockets were popping the capsule loose from the booster. Although Grissom peered out his window throughout his ship's turnaround maneuver, he never caught sight of his launch vehicle. Angular motion was perceptible to Grissom only by watching the needle move on the dial or by seeing an Earth reference by chance. Another cue to the spacecraft's movement was the Sun's rays, which gradually moved up his torso toward his face, threatening temporary blindness. Grissom fretted over the automatic turnaround that should have reversed the capsule faster.

With turnaround accomplished, the Air Force jet pilot for the first time became a space pilot, assuming manual-proportional control. A constant urge to look out the window made concentrating on his control tasks difficult. He told Shepard back in Mercury Control that the panorama of Earth's horizon, presenting an 800-mile arc at peak altitude, was fascinating. His instruments rated a poor second to the spectacle below.

Turning reluctantly to his dials and control stick, Grissom made a pitch movement change but was past his desired mark. He jockeyed the handcontroller stick for position, trying to damp out all oscillations, then made a yaw movement and went too far in that direction. By the time the proper attitude was attained, the short time allocated for these maneuvers had been used, so he omitted the roll movement altogether. The manual controls impressed Grissom as very sluggish when compared to the Mercury procedures trainer. Then he switched to the new rate command control system and found perfect response, although fuel consumption was high.[55]

After the pitch and yaw maneuvers, Grissom made a roll-over movement so he could see the ground from his window. Some land beneath the clouds (later determined to be western Florida around the Apalachicola area) appeared in the hazy distance, but the pilot was unable to identify it. Suddenly Cape Canaveral came into view so clearly that Grissom found it hard to believe that his slant-range was over 150 miles.

He saw Merritt Island, the Banana River, the Indian River, and what appeared to be a large airport runway. South of Cape Canaveral, he saw what he believed to be West Palm Beach. He tried to report to Shepard on the high-frequency

communications circuit every landmark he saw, but his transmissions were not received. These observations got Grissom behind in his work procedures, as he realized when he saw the periscope retract.

With *Liberty Bell 7* at an altitude of 118.26 miles, it was now time to position the spacecraft in its reentry attitude. Grissom had initiated the retrorocket sequence and the capsule was arcing downward. His pulse reached 171 beats per minute. Retrofire gave him the distinct and peculiar feeling that he had reversed his backward flight through space and was actually moving face forward. As he plummeted downward, he saw what appeared to be two of the spent retrorockets pass across the periscope view after the retrorocket package had been jettisoned.

Pitching the spacecraft over into a reentry attitude of 14 degrees from Earth-vertical, the pilot tried to see the stars out his observation window. Instead the glare of sunlight filled his capsule, making it difficult to read the panel dials, particularly those with blue lights. Grissom felt that he would not have noticed the .05-g light if he had not known it was about to flash on.

Reentry presented no problem. Grissom could not feel the oscillations following the g buildup; he could only read them on the rate indicators. Meanwhile he continued to report to the Mercury Control Center on his electric current reading, fuel quantity, g loads, and other instrument indications. Condensation and smoke trailed off the heatshield at about 65,000 feet as *Liberty Bell 7* plunged back into the atmosphere.

The drogue parachute deployed on schedule at 21,000 feet. Grissom said he saw the deployment and felt some resulting pulsating motion, but not enough to worry him. Main parachute deployment occurred at 12,300 feet, which was about 1000 feet higher than the design nominal altitude. Watching the main chute unfurl, Grissom spotted a six-inch L-shaped tear and another two-inch puncture in the canopy. Although he worried about them, the holes grew no bigger and his rate of descent soon slowed to about 28 feet per second. Dumping his peroxide control fuel, the pilot began transmitting his panel readings.

A "clunk" confirmed that the landing bag had dropped in preparation for impact. Grissom then removed his oxygen hose and opened his visor but deliberately left the suit ventilation hose attached. Impact was milder than he had expected, although the capsule heeled over in the water until Grissom was lying on his left side. He thought he was facing downward. The capsule gradually righted itself, and, as the window cleared the water, Grissom jettisoned the reserve parachute and activated the rescue aids switch. *Liberty Bell 7* still appeared watertight, although it was rolling badly with the swells.

Preparing for recovery, he disconnected his helmet and checked himself for debarkation. The neck dam did not unroll easily; Grissom tinkered with his suit collar to ensure his buoyancy if he had to get out of the spacecraft quickly. When the recovery helicopters, which had taken to the air at launch time and visually followed the contrails and parachute descent, were still about two miles

from the impact point, which was only three miles beyond the bullseye, Lieutenant James L. Lewis, pilot of the primary recovery helicopter, radioed Grissom to ask if he was ready for pickup. He replied that he wanted them to wait five minutes while he recorded his cockpit panel data. Using a grease pencil with the pressure suit gloves was awkward, and several times the suit ventilation caused the neck dam to balloon, but the pilot simply placed his finger between neck and dam to allow the air to escape.

After logging the panel data, Grissom asked the helicopters to begin the approach for pickup. He removed the pin from the hatch-cover detonator and lay back in the dry couch. "I was lying there, minding my own business," he said afterward, "when I heard a dull thud." The hatch cover blew away, and salt water swished into the capsule as it bobbed in the ocean. The third man to return from space was faced with the first serious emergency; *Liberty Bell 7* was shipping water and sinking fast.

Grissom had difficulty recollecting his actions at this point, but he was certain that he had not touched the hatch-activation plunger. He doffed his helmet, grasped the instrument panel with his right hand, and scurried out the sloshing hatchway. Floating in the sea, he was thankful that he had unbuckled himself earlier from most of his harness, including the chest restraints. Otherwise he might not have been able to abandon ship.

Lieutenant John Reinhard, copilot of the nearest recovery helicopter, reported afterward that the choppers were making their final approach for pickup. He was preparing to cut the capsule's antenna whip (according to a new procedure) with a squib-actuated cutter at the end of a pole, when he saw the hatch cover fly off, strike the water at a distance of about five feet from the hatch, and then go skipping over the waves. Next he saw Grissom's head appear, and the astronaut began climbing through the hatch. Once out, the pressure-suited spaceman swam away.

Instead of turning his attention to Grissom, Lewis completed his approach to the sinking spacecraft, as both he and Reinhard were intent on capsule recovery. This action was a conditioned reflex based on past training experience. While training off the Virginia beaches the helicopter pilots had noted that the astronauts seemed at home in and to enjoy the water. So Reinhard quickly clipped the high-frequency antenna as soon as the helicopter reached *Liberty Bell 7*. Throwing aside the antenna cutting device, Reinhard picked up the shepherd's hook recovery pole and carefully threaded the crook through the recovery loop on top of the capsule. By this time Lewis had lowered the helicopter to assist Reinhard in his task to a point that the chopper's three wheels were in the water. *Liberty Bell 7* sank out of sight, but the pickup pole twanged as the attached cable went taut, indicating to the helicopter pilots that they had made their catch.

Reinhard immediately prepared to pass the floating astronaut the personnel hoist. But at that moment Lewis called a warning that a detector light had flashed on the instrument panel, indicating that metal chips were in the oil sump




*Grissom is helped into* Liberty Bell 7 *by backup pilot Glenn.*

*Water-filled* Liberty Bell 7 *denies the helicopter's lift.*

**Flight of**
***Liberty Bell 7***
**July 21, 1961**



because of engine strain. Considering the implication of impending engine failure, Lewis told Reinhard to retract the personnel hoist while he called the second chopper to retrieve the pilot.

Meanwhile Grissom, having made certain that he was not snared by any lines, noticed that the primary helicopter was having trouble raising the submerged spacecraft. He swam back to the capsule to see if he could assist but found the cable properly attached. When he looked up for the personnel line, he saw the helicopter start to move away.

Suddenly Grissom realized that he was not riding as high in the water as he had been. All the time he had been in the water he kept feeling air escape through the neck dam. The more air he lost, the less buoyancy he had. Moreover, he had forgotten to secure his suit inlet valve. Swimming was becoming difficult, and now with the second helicopter moving in he found the rotor wash between the two aircraft was making swimming more difficult. Bobbing under the waves, Grissom was scared, angry, and looking for a swimmer from one of the helicopters to help him tread water. Then he caught sight of a familiar face, that of George Cox, aboard the second helicopter. Cox was the copilot who had retrieved both the chimpanzee Ham and Astronaut Shepard. With his head barely above water, Grissom found the sight of Cox heartening.

Cox tossed the "horse-collar" lifeline straight to Grissom, who immediately wrapped himself into the sling backwards. Lack of orthodoxy mattered little to Grissom now, for he was on his way to the safety of the helicopter, even though swells dunked him twice more before he got aboard. His first thought was to get a life preserver on. Grissom had been either swimming or floating for a period of only four or five minutes, "although it seemed like an eternity to me," as he said afterward.

As the first helicopter moved away from Grissom, it struggled valiantly to raise the spacecraft high enough to drain the water from the impact bag. Once the capsule was almost clear of the water, but like an anchor it prevented the helicopter from moving forward. The flooded *Liberty Bell 7* weighed over 5000 pounds, a thousand pounds beyond the helicopter's lifting capacity. The pilot, watching his insistent red warning light, decided not to chance losing two craft in one day. He finally cast loose, allowing the spacecraft to sink swiftly. Martin Byrnes, aboard the carrier, suggested that a marker be placed at the point so that the capsule might be recovered later. Rear Admiral J. E. Clark advised Byrnes that in that area the depth was about 2800 fathoms.

On the carrier *Randolph*, examining physicians Strong and Laning, the same men who had gone over Shepard, found Grissom extremely tired. But the MR–4 astronaut elected to proceed with his preliminary debriefing before going on to Grand Bahama. The recovery finale, of course, continually intruded in the discussion. Grissom said he was extremely grateful to Walter Schirra for the developmental work he had done on the neck dam. He felt that this had saved his life, although later tests disclosed other difficulties. The debriefing

sessions aboard the *Randolph* and at Grand Bahama centered on the need for more egress training (there had been none since April) and the formulation of specific emergency recovery procedures. Grissom said that he thought he should have been a little more precise in his attitude control functions. This was a moot point in view of the sluggishness he had encountered with the manual system and the apparent play in the control stick linkage. Other than this anomaly, the spacecraft had performed well; noises of the sequential events had provided good cues; vibrations had been minimal; the new window had been a delight and should prove useful on orbital flights; and the environmental control system had functioned well. But, said Grissom, there were too many couch restraint straps; the panel lights were too dim; the oxygen consumption rate was high; the urinal device needed further development; the high-frequency communication circuit was unsuccessful; and hydrogen peroxide fuel consumption proved to be high on the rate control system. The last item of that list caused little concern among the Space Task Group engineers, for they had decided that the rate command mode would be used primarily for reentry, when fuel economy was less important.

At Grand Bahama, Grissom rested and appeared to have suffered no abnormal effects from flight into space. The evaluators conceded, however, that the abnormal recovery experience would have made any such effects difficult to analyze or to attribute to flight causes. Further questioning of the astronaut followed the routine established in Shepard's debriefing.[56]

Obviously one of the major problems to be explained and resolved following the flight of *Liberty Bell 7* was the malfunction of the explosive egress hatch. Before the mission, Minneapolis-Honeywell had conducted environmental tests to qualify the hatch and igniter assembly. Although the tests had been run with the pin installed, conditions had been severe. The component had been subjected to low and high temperature ranges, a 100-g shock force, and salt-spray and water-immersion tests. After MR–4, the Space Task Group established a committee that included Astronaut Schirra to study the hatch problem. Tests were conducted in an environment even more severe than that used by the manufacturer, but no premature explosions occurred. Studies were made of individuals operating the panel switches on the side nearest the actuator; the clearance margin appeared to be adequate. According to Schirra, "There was only a very remote possibility that the plunger could have been actuated inadvertently by the pilot."

The mystery of Grissom's hatch was never solved to everyone's satisfaction. Among the favorite hypotheses were that the exterior lanyard might have become entangled with the landing bag straps; that the ring seal might have been omitted on the detonation plunger, reducing the pressure necessary to actuate it; or that static electricity generated by the helicopter had fired the hatch cover. But with the spacecraft and its onboard evidence lying 15,000 feet down on the bottom of the Atlantic Ocean, it was impossible to determine the true cause. The only

solution was to draft a procedure that would preclude a recurrence: henceforth the astronaut would not touch the plunger pin until the helicopter hooked on and the line was taut. As it turned out, *Liberty Bell 7* was the last manned flight in Project Mercury in which helicopter retrieval of the spacecraft was planned. In addition, Grissom would be the only astronaut who used the hatch without receiving a slight hand injury. As he later reminded Glenn, Schirra, and Cooper, this helped prove he had not touched his hatch plunger.[57]

## Titov Widens the Gap

Despite the loss of *Liberty Bell 7*, the Mercury-Redstone phase of the program had been so successful that there was little reason for keeping it alive. The termination of the manned suborbital flights had seemed predictable after Gagarin and certain after Shepard. A month and a half before Grissom flew, the Space Task Group had decided to cancel the fourth such flight, MR–6. Silverstein and Gilruth also had considered canceling the third flight, MR–5, to concentrate on Mercury-Atlas operations. But Silverstein believed that data obtained from Grissom's MR–4 should be appraised before deciding whether to bypass the MR–5.

Besides, at that time the subject was politically sensitive. Since three astronauts were training for the Mercury-Redstone missions, the public expectation, expressed in Congress and through the press, was that there would be at least three manned Redstone flights. But if Mercury-Atlas could be expedited, an astronaut making three orbits would eclipse the cosmonaut who had made one orbit.

On August 7, 1961, all such hopes were erased by the day-long, 17-orbit flight and successful recovery of Cosmonaut Gherman S. Titov. When the U.S.S.R. announced its spectacular second space flight, some Americans were filled with awe, some with admiration, and some even with fear, while a few expressed only scornful disbelief. At 9 a.m., Moscow time, on August 6, 1961, the Soviet pilot rocketed into orbit aboard *Vostok II*. The space voyage of this 26-year-old Russian covered 17.5 orbits and took 25 hours and 18 minutes.[58]

After the data gathered from the Grissom flight had been evaluated, NASA and Space Task Group managers decided that little could be gained from any further Mercury-Redstone missions. On August 14, Paul Purser drafted a termination recommendation for Gilruth's submittal to Silverstein. Purser pointed out that the Redstone had done well its job of qualifying the spacecraft, astronauts, and most other critical aspects of the operation. Mercury-Redstone also had validated the various training devices, and it had uncovered many technical problems, none of which appeared to be insoluble before an American orbital flight.[59] Now it was time to turn to the principal Mercury-Atlas problem areas, such as explosive hatch, inverter heating, oxygen usage rate, control system linkage, and egress training, and to cope with the more complex Atlas program. Four

days later, on August 18, NASA Headquarters publicly announced that the objectives of the Mercury-Redstone program had been achieved, and that accordingly it was canceled. Six days later, Joachim P. Kuettner, Mercury-Redstone Project Chief at the George C. Marshall Space Flight Center, told his subordinates that the Redstone must now be retired after helping gain a toehold on space.[60]

Several accounts of the Soviet manned space feats indicated striking similarities in cosmonaut and astronaut selection and training. The Russians were chosen by a strenuous selection program, which was much like the American procedure, but their selection emphasized youth and stamina, rather than flight experience and engineering. Soviet training, like American, employed the human centrifuge, altitude chamber, isolation, technical systems study, and personal physical training. Also, three pilots trained in competition for the first flight, Titov being Gagarin's backup pilot on *Vostok I* of April 12. Gagarin's and Titov's accounts of liftoff and orbital flight described the same phenomena—g-load buildup, vibrations, and impressions of weightlessness.

Titov was reported to have exercised manual control. This transliteration was taken in some circles to mean that he changed his orbital plane, but the Mercury experts believed that Titov's manual control was for attitude only, like that exercised by Shepard and Grissom. Titov reported sleeping seven hours or more, and some translations indicated that he was awakened by his weightless arms floating. This last claim was too much for David Lawrence, a syndicated columnist, who suggested that the flight might have been a hoax. But the members of the Space Task Group never doubted the authenticity of either *Vostok I* or *Vostok II*. Too much was similar. Although only two or three people in the Space Task Group could read Russian, the reports translated from Soviet journals seemed to correspond to their own experience.

One of Titov's publicized problems caused concern among NASA and Space Task Group medical specialists. Before entering his rest period, Titov complained of feelings "akin to seasickness" and became nauseated. He had to be careful not to move his head too swiftly in any direction. After sleep, his nausea apparently abated; it finally disappeared completely when Titov began to feel reentry pressures. NASA aeromedical advisers suggested that the first American in orbital flight ought to guard against, watch for, and test out this peculiar physiological reaction reported by Titov and the Soviets.[61]

Psychologically, the Russian Vostok feats created some uneasiness in the United States. Many people admired the Soviet's technological proficiency but were concerned by the strategic implications. The fact that Titov's orbital track in a near-polar plane carried him over the United States three times was alarming to some people. In spite of the fact that the decision for the accelerated space program was confirmed, the term "space lag" began appearing more frequently in the press and in the statements of some Congressmen. Criticism of NASA, the departed Eisenhower administration, and even the Kennedy administration mounted. After the Gagarin flight, for example, Democratic Senator Stuart

Symington of Missouri caustically pointed to the years of indecision that had so long delayed the Saturn launch vehicle. After the Titov flight, John W. Finney, aerospace and science writer for the *New York Times,* pictured Washington officialdom as carping over NASA's "easy pace" in implementing the lunar landing program outlined by President Kennedy. No specifications for a lunar spacecraft yet were evident; no agreement on the route to take or on the necessary launch vehicle had been reached. But these were mostly NASA Headquarters worries; the primary task of the Space Task Group still lay ahead. Regardless of the fact that Mercury could now only duplicate the feats of the Vostoks, Project Apollo, the manned lunar-landing project, depended upon Mercury Mark II (later named Gemini), the two-man rendezvous and docking project; and Gemini depended upon the fulfillment of Mercury; in turn, that depended upon the strength and stability of Atlas. The day Titov came back to Earth, NASA's Space Task Group announced candidly, if not calmly, that the first try at putting an American in orbit might slip unavoidably into January 1962.[62]

# XII

## Final Rehearsals

WITH the 1961 Labor Day holiday passed, the Space Task Group buckled down to an exceptionally busy season, one that was to be climaxed with STG's own demise and phoenix-like resurrection. Its activities had become farflung. Dead ahead, at Cape Canaveral, loomed the first orbital flight test of a Mercury capsule, carrying a true "black box," called a "crewman simulator," instead of an astronaut. Then, too, plans long had been ripening for a multi-orbital Mercury-Scout flight to qualify the ground tracking and communications network. A second orbital flight carrying a chimpanzee in the spacecraft couch also had an early place in the program.

Meanwhile NASA agents had completed an extensive survey of potential sites for the new development and operations installation for manned space projects of the future. At its Langley Air Force Base domicile, STG was busy planning for its expanding role in manned space exploration. Its personnel were weighing persistent rumors that the new Manned Spacecraft Center might be located in Texas, somewhere near the booming city of Houston.

The first objective of all this simultaneous activity was Mercury-Atlas 4, the fifth flight of an Atlas-launched spacecraft. This mission had been planned and replanned many times before the unsuccessful launch of MA–3 back in April 1961, and the failure of that mission directly affected the MA–4 plans. During the early months of 1960, MA–3 had been scheduled for a suborbital flight, with a crewman simulator aboard. First plans called for the Atlas booster to be held 150 feet per second below orbital velocity, with capsule separation occurring at the normal 100-mile-orbital-insertion altitude. Forty seconds after separation, retrofire was to have produced a landing beyond the Canary Islands and about 100 miles short of the African coast. And when this test was completed successfully, MA–4 was to repeat MA–3, but with a chimpanzee in the cockpit. Spacecraft No. 9 was to be specially fitted for the MA–4 flight.

Toward the end of 1960, however, Walter C. Williams advised the commanding officer of the recovery force, Destroyer Flotilla Four, that MA–4 would try for three orbits with a crewman simulator aboard and that the targeted launch date was April 1, 1961. But the MA–3 launch, still scheduled for a sub-

orbital flight with its "mechanical astronaut," slipped to April 25. While many Americans worried over the Soviet space coup represented by Yuri Gagarin's one-orbit flight on April 12, Robert R. Gilruth and Williams already had made the decision to change MA–3 to a one-orbit mission.[1]

April 25, 1961, came, but the day's recorded results were far from heartening. The MA–3 launch vehicle failed to program over into the proper trajectory; after 40 seconds of flight straight upward the Air Force range safety officer destroyed the Atlas booster. So it was necessary on MA–4 to strive for the same one-orbit objective and to delay still further the nominal three-orbit Mercury mission.

Meanwhile, for various reasons, production of the spacecraft and booster for MA–4 fell behind schedule. Atlas No. 88–D, allotted for MA–4, did not receive its factory rollout acceptance inspection until June 29–30, 1961, and it was July 15 before it was delivered to Cape Canaveral. And spacecraft No. 9 was not used, though originally planned. Instead No. 8 was fished from the Atlantic after its ill-fated flight in MA–3 and shipped back to McDonnell in St. Louis on April 27 for extensive overhauling. That meant cleaning, installing new insulation, replacing the external portion of the hydrogen peroxide control system, making spot-weld repairs in the large pressure bulkhead, and replacing the heatshield, antenna canister, escape tower, tower clamp ring, adapter, main clamp ring, and the inlet and outlet air snorkels. The overhauled spacecraft, redesignated 8–A, was returned to the Cape, but G. Merritt Preston's crew still had plenty of work. A leak had to be repaired in a reaction control system fuel tank; the environmental control system and the automatic stabilization and control system had to be reworked. A fairing to reduce launch vibration, like the one used on the Little Joe 5–B flight on April 28, 1961, and similar to that used on Virgil I. Grissom's suborbital mission in July, was added to the adapter clamp ring.[2]

Because of all this modification and overhaul, it was August 3 before the spacecraft for MA–4 was delivered to the pad and mated with the booster, supposedly to be launched on August 22. The day before the scheduled flight the Air Force's Space Systems Division in California called Cape Canaveral and reported that solder balls had been found in some transistors of the same brand that had been installed in the MA–4 booster. Coordination of this information among the various Mercury-Atlas teams at the Cape brought to light the fact that these types of transistors also had been used in the spacecraft. There was nothing left to do but postpone the launch and give both vehicles a thorough going-over to replace the defective transistors. On August 25 the spacecraft was returned to Hangar S, when it became apparent that this work might encompass several days. After these labors in the hangar, spacecraft 8–A was mated with the booster again on September 1. This time the engineers conducting the prelaunch checkouts found nothing wrong. Although 8–A was a secondhand capsule, its landing bag had not been installed, it had ports instead

of the new window, and the explosive egress hatch had been omitted, it still passed inspection.[3]

Besides the problem with the defective transistors, the Mercury-Atlas booster had been proceeding along the same tortuous route as the capsule toward flight qualification. By September, the Atlas had undergone so many changes that had to be integrated into launch vehicle No. 88–D, and experienced so many setbacks, that a successful orbital mission was necessary for the sake of NASA and national morale and to forestall any new attacks on the Atlas as the Mercury launch vehicle. The year in which the Soviets had orbited a man now was in its ninth month, yet the United States was still preparing to orbit a box full of instruments. The Mercury-Atlas flight record had produced only one completely successful launch—the MA–2 reentry heating test—out of four tries.

This was scarcely an enviable record. Many hours, days, and months had been spent by special committees and working groups in ferreting out the sources of trouble. The STG, Space Technology Laboratories, Convair, and Air Force engineers who had reviewed the failure of MA–1 had concluded that the forward end of the Atlas was not designed to withstand the flight dynamic loads fed through the adapter section, that the adapter was too flexible, and that stiffeners were needed. MA–2 had confirmed the controversial "fix" of the adapter section. MA–4 would be the second of the "thick-skin" Atlases. Reviewing the MA–3 abort, the engineers assumed that the programmer's failure to pitch the booster into a proper trajectory was due to a transient voltage. Also, some two years previously, another anomaly caused the Big Joe Atlas to fail to stage, and even in MA–2 there had been some propellant sloshing in the booster. To correct the programmer problem, Convair modified the autopilot controls to give the gimbaling engines of the Atlas a preventive counteraction capability. One objective of MA–4, therefore, was to assess this innovation.[4] In September the NASA-Air Force-contractor engineering team that had been beset with Atlas problems for two years felt that the ICBM-turned-space-launcher was ready to do its part in Project Mercury. In the words of Scott H. Simpkinson, STG's liaison man at the Convair factory, "MA–4 just had to work."

Not only would a successful orbital mission on MA–4 provide the necessary data on the performance of systems and components, but the Mercury tracking network crews and Department of Defense recovery forces would receive valuable training for supporting a manned orbital circumnavigation by an American. Many components, elements, procedures, and flight maneuvers had to be watched and assessed before one of the "Mercury seven" could be committed to an orbital mission around Earth.

Of the manifold segments of an orbital flight, reentry was perhaps the most critical. As it dropped back into the heavy atmosphere, the capsule would be subjected to searing temperatures of about 2000 to 3000 degrees F for six or seven minutes, or about eight times longer than on the previous Mercury suborbital shots. Retrofire between Hawaii and Guaymas, Mexico, would bring about a

gradual descent over the North American continent. About 345 miles east of Savannah, the first contact with atmospheric resistance would begin, at an altitude of 55 miles. At this point the appearance of the .05-g light on the panel would telemeter a signal that reentry was coming up. Peak aerodynamic heating would come when the spacecraft had descended to an altitude of 37 miles and was traveling at 15,000 miles per hour. Braking would be dramatic. Between 46 and 12 miles high, traveling over a slant range of 460 miles, the capsule's air speed would be reduced from about 17,000 to 1350 miles per hour. Aerodynamic stresses in this region would provide a severe test of the spacecraft's structural strength, particularly the heatshield and the afterbody shingles.

Perhaps the second most critical segment of the orbital mission would come during the powered phase of the flight. The Space Task Group, supported by the DOD and industry, would also monitor carefully the vibration levels to ascertain if they would be tolerable for an astronaut. Even more important as the capsule was rocketed toward orbit was a reliable escape system, to wrench the capsule clear if the launch vehicle failed to perform. Also it was necessary to judge the ability of the Atlas to release the spacecraft, to evaluate the abort sensing and implementation system, to determine if the launch vehicle could withstand the aerodynamic loads of max q, and to demonstrate the capability of the Mercury network to perform its intended flight-control and data-collection functions.[5] If all went well, MA–4 would provide data proving the validity of years of engineering calculations.

MA–4 would be launched from complex 14 at the Cape on a true azimuth heading of 72.51 degrees east of north. Following engine ignition, after being held to the pad for three seconds to ensure smooth combustion, the Atlas booster engines would propel the spacecraft within two minutes to a speed of about 6500 miles per hour and an altitude of 35 miles over a downrange distance of 45 miles. The sustainer engine would continue to burn. A gradual pitch program would begin to tilt the Atlas toward the sea about 20 seconds after liftoff. Seconds after booster engine cutoff (called "BECO" by the various Mercury-Atlas working teams at the Cape), or at about 41 miles' altitude and a slant range of 56 miles from the pad, the launch vehicle programmer would trigger a greater pitch-over maneuver to put the Mercury-Atlas combination on a course parallel to Earth's surface. At this time the escape tower would be jettisoned. After capsule separation, orbital insertion would occur about 498 miles downrange from the pad at an altitude of about 100 miles. The nominal inertial velocity at this point was supposed to be 25,695 feet per second, increased to 25,719 feet per second by the ignition of the posigrade rockets, which separated the spacecraft from the booster. Within 50 seconds, the spacecraft should have drifted some 790 feet from the booster. The Atlas, rather than falling away, would trail the orbiting spacecraft around Earth at an altitude of about 100 miles, and should complete each circle about once every 90 minutes for an estimated three days.[6]

Instrumentation affixed to the spacecraft would provide data from nearly

every conceivable point about the capsule. Noise levels in the vicinity where an astronaut's head would rest would be measured and recorded on magnetic tape. Excess vibration, a problem during early Mercury-Redstone flights, would be monitored closely by seven strategically placed sensors, mostly in the area where capsule and adapter joined. To determine what radiation dosages a pilot would encounter, four standard and two special film packs would be carried. The standard packs were placed on the sides and at the top and bottom of the couch. Carrying a heavier emulsion, the two extra packs would measure the radiation spectrum—the range of all kinds of radiation to which the capsule would be exposed—as well as penetration levels. Flight data other than radiation would be transmitted by two separate telemetry links, each providing essentially the same information.

The flight would be well covered photographically. Located on the left side of the capsule cabin was the instrument panel camera, which would start operating at liftoff, provide about 20,000 frames of panel information during the mission, and cease five seconds after impact. Placed near the right-side port, the Earth-sky camera was loaded for about 600 frames of pictorial data, which would be exhausted somewhere over the Indian Ocean. A third camera, affixed to the periscope, was loaded with about 10,000 frames of film for the mission. This camera would provide especially useful information on the spacecraft's orbital attitude reference to Earth at points where landmarks were recognizable.

Five recorders aboard the spacecraft would tape most of the mission data. Three were seven-track systems to record all telemetry outputs, vibration levels, noise, and shingle strain. The two others were single-track recorders, to be operated in tandem and used to check the reliability of the tracking network communications system.[7]

Plans for spacecraft operations after the powered phase were essentially the same as those for the suborbital flights, only on a much larger scale. Retrofire was scheduled at 1 hour, 29 minutes, and 4 seconds after launch, with the three rockets firing at five-second intervals in order: top-left, bottom, top-right.[8] Recovery plans for orbital missions were considerably more complicated than they had been for the suborbital flights, since many more contingency areas, including abort and overshoot, had to be considered. Besides the nominal landing area off the coast of Bermuda, five secondary landing areas were selected. Providing that the launch was nominal and proceeded according to the preflight calculated trajectory, the abort recovery areas were spaced as follows: Area A began about 13 miles from the launch pad and continued along the track for 2200 miles. For the first 550 miles the coverage extended 30 miles to each side of the track. This area covered the first 72 seconds after launch, or through booster staging. The remainder of Area A, accounting for the period up to 298 seconds after launch, narrowed to about 15 miles on either side of the track. Areas B and C were small elliptical blips on the track, 4 and 8 degrees of longitude beyond A. These were designated for a possible abort at 298 or at 301 seconds, respec-

tively. The third contingency site, Area D, was a longer ellipse (20 by 122 miles) beginning about 7 degrees of longitude past C. At this point the "go/no go" flight decision would be made. The last, Area E, an ellipse 24 by 231 miles along the track, covered aborts up to 304 seconds after the go/no go decision.[9]

The MA–4 capsule also was fitted with a number of aids to assist the DOD forces in their recovery task. Two one-pound sofar bombs, one set to eject upon main parachute deployment and the other set to detonate at 4000 feet of hydrostatic pressure if the spacecraft sank, were carried. A flashing light with a life of about 24 hours was set to activate upon impact. Fluorescein dye, ejected at touchdown, would be visible for about six hours. Navy recovery forces were asked to attempt the recovery of the drogue and main chutes and the spacecraft antenna canister. Balsa wood blocks and Styrofoam had been attached to these components for flotation.[10]

As the launch date of the Mercury-Atlas 4 combination neared, weather problems began to threaten this attempt to orbit a "mechanical astronaut." Not one but two hurricanes thrashed the Mercury tracking areas. "Carla" raked the Corpus Christi tracking station, while "Debbie" moved in a northerly direction on the day before the launch, menacing and causing the ships to get rather a "rough ride" in the prime recovery zone. The equipment at the Texas site withstood the storm without damage. The STG-Air Force-Navy recovery planners at the Cape felt that Weather Bureau support predictions had given them a sufficient margin of safety in the Atlantic to allow the mission to proceed.[11]

## Mercury Orbits at Last

On launch day, September 13, the cloud coverage was scattered; visibility was 9 miles; the wind velocity was about 11 miles per hour; and the temperature was 78 degrees. Ninety minutes before launch time a half-hour hold was called to replace a broken screw in one of the afterbody shingles. The liquid oxygen was loaded by 8:30 a.m., and 5 minutes later the operations crew determined that all systems were go. At 8:57, however, the low-speed data timing was momentarily lost at the Bermuda tracking site, and the countdown was recycled to T minus 3 minutes and 30 seconds.

A little after 9:04 a.m. on September 13, 1961, MA–4 was launched on its one-orbit mission. During the first 20 seconds from liftoff, fairly severe booster vibrations were detected by the flight dynamics officer in the Control Center. The "thick-skin" Atlas passed its max-q test. At the 52-second point, a spacecraft inverter that was converting electrical power from direct to alternating current failed, but the standby inverter switched on automatically. Guidance data soon disclosed that the trajectory was .75-degree high; later, at engine cutoff, it was .14-degree low. Although booster engine cutoff occurred 2.5 seconds early, booster velocity was about 100 feet per second too high. Then the sustainer engine cut off 10 seconds early, so the desired velocity was essentially achieved.

Despite these dispersions, which were within design limits, perigee and apogee of the orbit were only slightly more than a mile and 12 miles, respectively, below plan. The Goddard computers instantly indicated a go for the mission. The powered phase, plus posigrade rocket increment, provided a peak velocity of 25,705 feet per second; g loads during the powered phase reached a peak of 7.6.[12]

Despite a slight disturbance in the roll, pitch, and yaw of the booster, separation occurred properly, and after a 5-second steadying or damping period the capsule began its turnaround maneuver. Soon, however, large attitude excursions were observed, and the spacecraft took 50 seconds to reverse its ends to heatshield forward, as opposed to a normal 20 seconds, using 9.5 pounds of hydrogen peroxide attitude control fuel against the 2.2 pounds supposedly required. Even with the abnormal turnaround, the spacecraft attitude gyros and scanners soon transmitted nominal readings, and there seemed no doubt that the mission would proceed to its orbital conclusion. The cause of these undue excursions later was found to be an open electrical connection in the pitch-rate gyro.[13]

A high oxygen usage rate like that on Grissom's suborbital mission cropped up early and continued throughout the flight. At the 27,000-foot point the system sealed off at 5.5 pounds per square inch; then an abrupt drop was indicated in the primary oxygen supply and a concurrent rise in cabin and suit pressure values to 6 pounds per square inch. "Primary oxygen going down fast," Paul E. Purser jotted in his notes as he listened to the communications circuit. "Zanzibar reported 30 percent of primary oxygen left," he later added. Toward the end of the mission, with the primary supply depleted, the system switched over to secondary. Usage from this source was so slight, however, that Walter Williams, commenting on the high usage problem in a press conference following the mission, said that the secondary supply was virtually untouched. Throughout the flight the crewman simulator continued to use oxygen to produce moisture and carbon dioxide, and to monitor the operations while recording heat and suit pressure changes.[14]

Despite the abnormalities with the oxygen supply, once the automated Mercury spacecraft was on its orbital course, the computers indicated that the mission could go for more than seven orbits. In general, the control systems operated well, although on three occasions the spacecraft dropped out of its 34-degree, Earth-reference mode, once just before the ignition of the retrorockets and twice just before the .05-g light telemetry signal. These attitude variations came from the failure of a one-pound yaw-positive thruster and a one-pound roll-negative thruster.

Communications between the capsule and the tracking stations were good, especially on high frequencies, which on the earlier suborbital flights had been virtually unsuccessful. In some cases radar tracking was not good, largely because a few of the operators lacked experience. Telemetry reception was excellent, with some 137 observations received by the various tracking stations during the flight.[15]



*Crewman simulator checks spacecraft conditions during the flight.*

*Flight monitors in the blockhouse: left to right, Ralph B. Gendielle of McDonnell, and Donald D. Arabian and Walter J. Kapryan of NASA's Space Task Group.*



**MA–4**
**Sept. 13, 1961**



*Inspecting the heatshield after the flight: kneeling, left to right, William C. Hayes, of STG; John F. Yardley, of McDonnell; and Charles W. Mathews, Samuel T. Beddingfield, G. Merritt Preston, all of STG.*

One hour, 28 minutes, and 59 seconds after MA–4's liftoff, the first retrorocket fired in the vicinity of Hawaii. Monitors at the Guaymas station in Mexico indicated that retrofire, triggered by the spacecraft clock, had gone off as planned. Within the range of the Cape Canaveral control center, telemetry data disclosed that MA–4 was in the proper reentry attitude. Over the Atlantic the drogue parachute opened at 41,750 feet, and the main chute deployed at 10,050 feet. At 10:55 a.m. the capsule splashed down 176 miles east of Bermuda. After an hour and 22 minutes, the destroyer *Decatur*, which had been about 34 miles from the impact point, pulled alongside the spacecraft and hoisted it aboard. From there the capsule and its robot "astronaut" rode to Bermuda, whence they were airlifted to the Cape for an exhaustive examination.[16]

The cause of the oxygen supply malfunction was immediately attacked by the STG and McDonnell engineers. Onboard film, they found, disclosed that the oxygen supply emergency light had blinked on, which would have signaled an astronaut to take corrective action. The inspectors also learned that vibration had dislodged the rate handle from its detent, allowing a valve to crack open. But the flow rate had not been sufficient to trip the microswitch that would have given the Mercury Control Center a telemetry indication of an emergency rate actuation while the mission was in progress. Normally a force of from three to eight pounds was needed to break the handle free from the detent, whereas in this case the inspectors moved the handle with very little force. A new emergency rate handle with a positive latching mechanism was to be devised for later missions.[17]

Other postflight analyses by the engineers found the MA–4 spacecraft and its systems in good condition. There was no afterbody shingle buckling or warping, and the structural materials were only mildly discolored. The horizon scanner window was partially coated with a film of oxidized material caused by aerodynamic heating. Some internal debris, including solder balls and washers, had apparently escaped preflight tumbling and vacuum cleaning. Six buckled skin panels between the base ring and the lower pressure bulkhead indicated that the capsule landed with the heatshield edge striking the water first. Still the inspectors concluded that the structural damage was not enough to have endangered an astronaut. The center section of the heatshield was partially delaminated and the center plug was loose, conditions apparently caused by water impact and cooling. Two cracks were found on the shield in the vicinity of the water-impact point. The depth of the char on the ablation shield was very shallow.[18]

NASA officials showed their pleasure at the success of MA–4 at the press conference held at the Cape immediately after the flight. Gilruth pointed out that this had been the hardest test flight in the whole NASA program. He added that the Atlas had demonstrated that it was capable of boosting a man into orbit, as he, Maxime A. Faget, Purser, and others from NACA-Langley days had long believed. Without hesitation Gilruth concluded that a man would have survived the flight.



*Above, architect's conception of the new NASA Manned Spacecraft Center, Houston, Texas, as of early 1962. Right, the Center under construction as of the end of Project Mercury, May 1963. The structure in the center is the administration building.*

At that point a reporter asked whether a man would fly the next Mercury orbital mission. Walter Williams answered that a three-orbit circuit, either unmanned or carrying a chimpanzee, was still necessary. Then why was the upcoming Mercury-Scout mission necessary, asked a newsman. Again Williams affirmed his confidence in the wisdom of the agreed-upon schedule of flights.[19]

## Space Task Group Gets a New Home and Name

Between flight planning and scheduling launches in August 1961, a NASA site survey team headed by John F. Parsons, Associate Director of Ames Research Center, had inspected a number of sites competing for the permanent location of a center for manned space flight projects. The new center had been approved in principle by President Kennedy in accordance with his strategic decision, endorsed by the Congress, to accelerate the space program. The team appraised the sites on 10 points, briefly stated as follows: availability of educational institutions and other facilities for advanced scientific study, electric power and other utilities, water supply, climate, housing, acreage, proximity to varied industrial enterprises, water transportation, air transportation, and local cultural and recreational resources. On September 19, 1961, NASA Administrator James E. Webb announced that the new Manned Spacecraft Center (MSC) would be established on a 1000-acre tract to be transferred to the Government by Rice University, near Houston. The site was in Harris County, Texas, on the edge of Clear Lake, an inlet of Galveston Bay on the Gulf of Mexico.[20]

Webb maintained that selection of the Houston site had been influenced by



recent decisions to expand the launch complex at the Atlantic Missile Range and to establish a fabrication facility for large booster and space vehicle stages at the Michoud Plant, near New Orleans, where torpedo boats had been manufactured during World War II. The Manned Spacecraft Center, the Michoud Operations, and the Cape Canaveral complex would become a vast integrated enterprise coordinating the development, manufacture, and operation of the manned space flight program.

Not unexpectedly, there was some criticism of the Texas site chosen for the new development center. Charges of inordinate political influence involved the names of Vice-President Johnson, a Texan and chairman of the National Aeronautics and Space Council, and Democratic Representative Albert Thomas of Houston, Chairman of the House of Representatives Independent Offices Subcommittee of the Appropriations Committee. NASA spokesmen categorically denied that there had been any improper influence. Particularly crestfallen were the citizens of the Virginia peninsula, who realized they were losing some of the activities at the Langley Research Center and the Wallops Station. All through August, September, and October, the dailies of Newport News echoed this disappointment. To Houston, of course, this was "wonderful news," as the Chamber of Commerce proclaimed, and local business leaders dispatched representatives to brief the transferring NASA employees in Virginia on the advantages of the Texas coast.[21]

Less than a month after Webb's announcement, a Houston journalist went on an inspection tour of the site planned for the spacecraft center. He found cowboys driving herds of cattle to new pasture, a crew of surveyors from the Army Corps of Engineers mapping the prairie near Clear Lake and fighting snakes, and a lone wolf hunter with the carcass of a freshly slain wolf. The hunter said he had just seen several wild turkeys, a fox, and many deer tracks.[22]

Gilruth and other officials of the Space Task Group reacted quickly to the Webb announcement. The very next day they flew into Houston to begin a search for an estimated 100,000 square feet of temporary floor space. Moving began in October 1961, when Martin A. Byrnes, as the local manager, and a small cadre of center operations, procurement, and personnel employees opened offices in Houston's Gulfgate Shopping City. By mid-1962, when the move was completed, activities were scattered in 11 locations, occupying 295,996 square feet of leased office and laboratory space in the vicinity of Telephone Road and the Gulf Freeway. For both old and new employees, a street map was a necessity in the coordination of information among the various offices located in the dispersed buildings. Besides the leased quarters, NASA personnel liberally used surplus facilities available at nearby Ellington Air Force Base.[23]

By early October 1961, the Space Task Group had established an information relocation center in its Public Affairs Office to help personnel facing the move. Inquiries from the employees about schools and housing were numerous. Shortly thereafter, members of the Space Task Group received procedure directions for permanent change of duty station and then were advised on November 1, 1961, that "the Space Task Group is officially redesignated the Manned Spacecraft Center." The center was now a de facto NASA unit, a nerve center of the accelerated manned space flight program. It was several months, however, before the administration of projects was subdivided for management of the three major programs—Mercury, Gemini, and Apollo. NASA outlined its building requirements for the center on October 13, 1961, at which time two plans were under consideration, one with 13 major buildings and the other with 14, to accommodate 3151 people. The estimated cost was $60 million for the first year's construction.[24]

## Wires Get Crossed: Mercury-Scout I

Despite the flurry of activity at Hampton, Virginia, Houston, and elsewhere, generated by the impending move, STG did not pause in its scheduled Mercury flight test program. Plans had been in progress for several months and by the summer of 1961 were well developed for Mercury-Scout, whose flight was to provide a dynamic checkout of the Mercury tracking network.

Early in May, Purser and Williams of STG, Charles J. Donlan, who had returned to the Langley Research Center rolls in April, and Warren J. North of NASA Headquarters had met to discuss how the Mercury tracking network, completed at the end of March, could be exercised and evaluated. They agreed that the four-stage, solid-propellant Scout, originally designed at Langley and popularly called the "poor man's rocket," could perform this task economically. North briefed Abe Silverstein, NASA Director of Space Flight Programs, when he returned to Washington from Langley. In the meantime, William E. Stoney of STG had inquired of the Air Force, which also used the Scout, about the

availability of a Scout launch vehicle. The planners proposed to use the Air Force and its contractors for payload design and construction and for vehicle assembly and launch. On May 11, Air Force officials replied that a Scout was available, but concurrently North reported that Silverstein was not interested in a Scout shot. Purser, relaying this information on to Gilruth, remarked that "you or Williams will have to talk to him [Silverstein] about it." Mercury-Scout mission planning, meanwhile, was already in progress, and Marion R. Franklin of STG was temporarily appointed as project engineer. This responsibility took on the aspects of a revolving door, with the assignment being shuffled among several Task Group engineers. James T. Rose was named to head the project a few days later; then Rose and Lewis R. Fisher had co-responsibility, until Rose was relieved to continue his work with James A. Chamberlin on what became the Gemini two-man spacecraft project proposals.[25]

Although Silverstein at Headquarters opposed such a test, those on the operations end of Mercury felt that a flight to train the operators and check the tracking stations was a necessity. On May 15, 1961, personnel of NASA Headquarters and several of its cognizant centers, including Harry J. Goett of Goddard, Williams and Purser of Space Task Group, Low from NASA Headquarters, and Thomas A. Harris, G. Barry Graves, and Paul Vavra from Langley, met to review the proposed Scout launch in view of Silverstein's reluctance. They still concluded that the Scout was the best booster for network checkout purposes. The problem was how to sell the idea to Silverstein.

Low and Graves saw Silverstein the next day. They told him that only a one-orbit flight, possibly carrying a chimpanzee, was scheduled for the next six months; moreover, the Air Force had a spare research and development Blue Scout booster. This readiness gave promise of a reasonably early launch date, which was necessary if the communications exercise were to be worthwhile. Silverstein tentatively acquiesced, but he demanded assurance that all the design problems, including payload and antennas, would be resolved before he gave final Headquarters approval. After that approval, he added, all effort should be made to meet an August 15, 1961, firing date.[26] This stipulation apparently was made so that the flight would precede the scheduled August 22 launch date of the MA–4 one-orbit flight.

With Silverstein's reluctant blessing, the planners wasted no time in getting the Scout enterprise rolling. At a meeting at Langley on May 17, attended by Williams, Purser, Merritt Preston, Franklin, and Chamberlin of STG; North of NASA Headquarters; and Graves, Virgil F. Gardner, and Elmer J. Wolff of Langley, responsibilities were assigned and some general requirements were outlined. As noted, Rose and Fisher were named project engineers. Rose was in Los Angeles discussing boosters for the two-man project at the time. He received a call from Chamberlin requesting him to go to Aeronutronic in Newport Beach, California, to talk about instrumentation for the payload. He was joined there by Earl Patton, communications expert from McDonnell Aircraft Corporation.

Graves asked the Goddard Space Flight Center to supply minitrack equipment and Goddard tentatively agreed to do so. The purpose of the minitrack equipment (used in the instrumented satellite programs) was to furnish data for comparison with that which would be transmitted by Mercury instrumentation. Mercury instrumentation was to include C- and S-band beacons, telemetry carriers, and either a command channel on the minitrack or a receiver operated by a command transmitter. Graves also planned to arrange with Goddard for minitrack drawings, and Chamberlin volunteered to contact McDonnell for the Mercury instrumentation drawings and hardware components. Some thought was briefly given to the possibility of using the Langley Research Center to instrument the payload; otherwise the Ford Motor Company's Aeronutronic Division, Air Force contractor for the Scout, probably would provide the instrumentation.[27]

On May 23, North in Washington telephoned Purser at Langley and reported that Silverstein "had bought the Scout." There was a qualification, however: planning could proceed, but money was not to be committed until Robert C. Seamans, Jr., NASA's "general manager," approved. Silverstein immediately sought Seamans' concurrence, offering the inducement that only the payload would require NASA funding ($130,000); the Air Force, using the operation to provide experience for its launch crews, would bear the cost of the launch vehicle and launch. Silverstein argued to Seamans that delays in the Mercury-Atlas program, with a reduction of the flights to be conducted before a manned orbital mission, made using the Scout to check out the network seem sensible. The proposed payload, he said, would be prepared by Ford Aeronutronic, using components from Mercury capsule No. 14, which had already flown in the Little Joe 5–B test of April 28, 1961. The STG planners estimated that the earliest possible launch date was sometime in July, but Silverstein told Seamans that an August date seemed more realistic. Seamans agreed and returned the formal STG request on May 26, stamped "approved." [28]

Now that the blessing was official, the Space Task Group made a sustained effort to launch in July. In June STG engineers considered the components that were to make up the 150-pound payload. Since Associate Administrator Seamans at NASA Headquarters had suggested in his approval document that a backup launch vehicle be obtained, STG secured the Air Force SSD's commitment to supply a second four-stage Scout. Seamans' suggestion proved to be prophetic; although no second Mercury-Scout mission was ever launched, the backup fourth stage had to be used in the first attempt.[29]

By early July, the trajectory data and mission directive for Mercury-Scout were completed. MS–1 would be launched at the Cape from complex No. 18–B, formerly the Project Vanguard launching site, on a true azimuth heading of 72.2 degrees east of north, aiming at an apogee of about 400 miles and a perigee of about 232 miles. Orbital insertion of the payload was to occur some 1100 miles from the Cape, at a speed of 25,458 feet per second and an altitude of

232 miles. A small rectangular box held the payload, which consisted of a C- and S-band beacon, two minitrack beacons, two command receivers, and two telemetry transmitters, all with antennas; a 1500 watt-hour battery; and the fourth-stage instrumentation package. The payload equipment was to function for 18½ hours in orbit. To conserve electrical power while in flight, the equipment would be turned off by a ground command after the first three orbits. During shutdown, the results would be analyzed, and the equipment would then be activated to make another three-orbit data collection. The planners felt that by repeating the shutdown and reactivation operation they could obtain data equivalent to three full missions, gather a wealth of information for comparison, and give the DOD and NASA trackers a good workout.[30]

The launch vehicle for the mission was a 70-foot, solid-propellant Scout rocket weighing 36,863 pounds at liftoff. The booster had four stages. Starting from the bottom, these included an Aerojet Algol engine with a steel case and steel nozzle, burning polyurethane fuel and guided by hydraulic exhaust vanes; a Thiokol Castor motor, also with steel case and nozzle, burning a polybutadiene-acrylic acid propellant, with a precision autopilot employing hydrogen peroxide reaction motors; an Allegheny Ballistic Laboratories Antares motor encased in filament-wound fiber impregnated with epoxy resin, propelled by nitrocellulose nitroglycerin, and guided by an autopilot identical to that in the Castor; and an Allegheny Altair engine of the same construction as stage 3, using the same propellant, but with a spin-stabilizing control mechanism.[31]

The Scout was erected on the pad on July 25 to await mating with the payload. Ford Aeronutronic had completed what turned out to be the initial packaging and had shipped the payload to the Cape on July 3. There the equipment underwent spin-ballast and operational checks and was mated with the booster. But trouble with faulty solid-state telemetry transmitters, developing during the pad checkout, caused such a delay that a July launching became impossible. At about that same time NASA Headquarters decided that the payload had not had sufficient vibration testing, so it was shipped to Aeronutronic at Newport Beach, California, for testing and repackaging. After it returned to the Cape, malfunctions appeared in the Scout's fourth stage, and the Cape engineers had to lift the fourth stage from the backup vehicle. The question in August was which would be ready first, the launch vehicle or the payload. Then on September 13, MA–4, carrying its mechanical astronaut, essentially preempted the Mercury-Scout by its orbital trek around Earth. The Scout payload reached the Cape on September 20, but all four Scout stages did not return to the pad until October 22. The anticlimactic Scout launch was supposed to take place on the 31st.[32]

On Halloween, 1961, a launch crew under the technical supervision of the Air Force launch director (who, in turn, was responsible to the NASA operations director) attempted the Mercury-Scout launch. The countdown proceeded well down to the moment of ignition—when nothing whatever happened. The

**MS–1**
**Nov. 1, 1961**









ignition circuits were rechecked and repaired and the next day, November 1, 1961, Mercury-Scout took off. Immediately after liftoff, the vehicle developed erratic motions, and after 28 seconds the booster began tearing apart. The range safety officer gave the destruct signal 43 seconds after launch. The failure, it was later determined, resulted simply from a personal error by a technician who had transposed the connectors between the pitch and yaw rate gyros, so that yaw rate error signals were transmitted to pitch control, and vice versa.[33] Six months of plans and labors had disintegrated in less than a minute.

Ambitions for a second Mercury-Scout, such as had been advocated earlier by Seamans, collided with the reality that another Scout rocket would not be ready before a Mercury-Atlas launch afforded a satisfactory and complete ground-tracking network checkout. The first stage of the backup Scout rocket failed its inspection tests, while the fourth stage had been used on the ill-fated Mercury-Scout 1 mission. Besides, Mercury-Atlas 5 was scheduled to go in mid-November, and the first manned orbital mission was set for December 19. Consequently, Low recommended the cancellation of the Mercury-Scout program to D. Brainerd Holmes, who had taken on manned space flight duties in NASA Headquarters.[34] So the Scout had a short but chaotic life as a member of the Mercury family of launch vehicles.

## Man or Chimpanzee for MA–5?

From its unseemly beginning embodied in the Mercury-Scout failure on the first day of its formal existence, the newly titled Manned Spacecraft Center would go on in November to direct and record a resounding success, Mercury-Atlas 5. A curious atmosphere surrounded the approaching animal orbital mission, a sense of impatience, as though the Nation wanted to see it done quickly so the program could hurry forward to a manned orbital shot. The press clearly deplored any slip in MA–5 that would delay the manned flight. Putting an American into orbit before the end of 1961 was popularly regarded as something sorely needed for national prestige. NASA officials obviously were influenced by these pressures, and rank-and-filers in the space program were like members of a football team committed to a warmup game before a conference classic.[35]

Some NASA leaders flatly opposed the chimpanzee flight. Administrator Webb's office questioned MSC on the need for another unmanned Mercury mission in view of the successful orbital flights of Cosmonauts Gagarin and Titov. A Washington newsman suggested that the President's advisers feared another American animal flight would only invite Soviet ridicule. Paul P. Haney, a public-affairs spokesman at NASA Headquarters, finally cleared the air when he announced to the public, "The men in charge of Project Mercury have insisted on orbiting the chimpanzee as a necessary preliminary checkout of the entire Mercury program before risking a human astronaut." [36]

Other space-related events soon distracted public attention from the impend-

ing primate voyage on MA–5. One was the perfect launching of the mammoth Saturn I on its maiden flight. On the morning of October 27, the 163-foot-tall vehicle, with its 1.3 million pounds of thrust, rocketed 215 miles into space. The flight immediately triggered public discussion of whether a super-Saturn might be selected for launching the lunar mission spacecraft.[37] In Houston, the Manned Spacecraft Center, site for the direction of manned space projects of the future, captured the imagination of local citizens. A space-age tradition was born when H. T. Christman, a procurement officer, became the first member of the organization to buy a home in the Houston area, which was located in the Timber Cove residential development that was to become the neighborhood of several Mercury astronauts, near the site of the to-be-constructed Spacecraft Center.

Preparation for MA–5, initiated many months previously, continued without much fanfare. As early as January 1961, notes on the status of hardware for this mission had begun to appear in STG's quarterly progress reports to NASA Headquarters. Both booster and spacecraft then were being manufactured and tested. On February 24, spacecraft No. 9 had arrived at the Cape to begin a 40-week preflight preparation. This lengthy period, longest in the Mercury project, derived from the various flight program changes that required corresponding configuration changes. No. 9 had been configured initially for a ballistic instrumented flight, then for a ballistic primate flight, next for a three-orbit instrumented mission, and finally for a three-orbit chimpanzee flight.[38]

Another factor contributing to the long preparatory period was that the data obtained from the MA–4 mission demanded a number of modifications. For the environmental control system, a locking device was added to the oxygen emergency rate handle, while the inverters, one of which had failed during MA–4, were put through a severe vibration-test program. Since some unbonding had occurred on the heatshield of the MA–4 spacecraft, x-rays twice were made of the ablative layer to determine the soundness of the glue line. For the explosive side egress hatch, as yet untried on an orbital mission, thermocouples were added and a limit switch was installed to signal any premature hatch firing, an experience that cost the loss of a flight-tested spacecraft in MR–4. And the horizon scanner sensor system was modified to avoid the erroneous signals transmitted during the orbit of the "mechanical man."[39]

Thus the spacecraft mounted on Atlas No. 93–D for MA–5 differed considerably from that used on the September orbital flight. This was another reason Haney had said that "the men in charge of Project Mercury" wanted another qualifying round before a manned mission. Besides modifications already described, No. 9 had a landing bag installed and a large viewing window. Although the window had been used on MR–4 and had proved useful to Astronaut Grissom, it had not been subjected to the much greater reentry heat the MA–5 capsule would encounter. Aside from these new components, No. 9 had about the same equipment as carried in MA–4—tape recorders for gather-

ing data and exercising the communications network, cameras, and radiation film packs. Of course, "Enos," the chimpanzee eventually selected from the colony in training, would need no simulator to do his breathing or perspiring. He had his own metal-plastic pressure couch, which was connected to the suit circuit of the environmental control system.[40]

The spacecraft operated in a fashion similar to the first orbital Mercury vehicle. Once again, as during MA–4, the hydrogen peroxide fuel supplies for the automatic and manual control systems were linked to provide a common reservoir. The automatic stabilization and control and rate stabilization control systems would be operated separately, so that the performance of each could be evaluated. The automatic system was programmed to exercise capsule attitude control until one minute after the .05-g light signal; then the rate system would take over for reentry, providing a constant-roll rate of about 7.5 degrees per second as well as damping motions in the yaw and pitch axes. The rate system would switch off at main parachute deployment.[41]

Recovery aids and operations, too, were about the same as for MA–4, including radar chaff, sofar bombs, a flashing light, and dye marker. The probable launch abort recovery areas were spaced and designated as before, although there were more contingency recovery areas because the mission was longer. For each of the three planned orbits about five contingency locations were selected. During the second orbit, for example, the emergency landing areas included the Atlantic Ocean near the west coast of Africa, the Indian Ocean near the east coast of Africa, the Indian Ocean near the west coast of Australia, and the Pacific Ocean either 440 miles southeast of Hawaii or 165 miles southwest of San Diego. The primary recovery zone shifted following the completion of each full orbit.[42]

Space Task Group officials expected delivery of the MA–5 launch vehicle, Atlas No. 93–D, about mid-August 1961, but it was decided by STG and the Air Force to delay shipment until the flight of MA–4. Then, when faulty transistors had delayed the MA–4 launch, intensive quality assurance inspections of the transistors had to be initiated. The electronic gear of the rocket was also modified, its 100-watt telemetry system was replaced by a 3-watt transistorized unit, and the autopilot circuitry was altered to alleviate the high vibrations experienced during the first orbital Mercury flight. These changes dragged the delivery date back to October 9, 1961. In Washington, George Low warned Seamans that the time needed to secure several components necessary for these modifications might affect the delivery date of Atlas No. 109–D, the booster scheduled to launch the first astronaut into orbit. No. 93–D was the third "thick skin" Atlas booster, employing a heavier gauge of metal in its forward tank.[43]

According to plans, which now were to approximate those for the manned orbital mission as nearly as possible, MA–5 would rise from complex 14 at Cape Canaveral on a heading 72.51 degrees east of north. Orbital insertion of the

spacecraft should occur about 480 miles from the Cape at an altitude of 100 miles and at a speed of about 25,695 feet per second. Retrofire to initiate entry into the atmosphere was planned for 4 hours, 32 minutes, and 26 seconds after launch. Twenty-one minutes and 49 seconds later the spacecraft should hit the water in the Atlantic. Estimated temperatures during reentry should be about 3000 degrees F on the heatshield, 2000 degrees on the antenna housing, 1080 degrees on the cylindrical section, and 1260 degrees on the conical section. The STG operation planners estimated that the spent Atlas sustainer engine would reenter the atmosphere after 9⅓ orbits, a considerable change from their estimates for the descent of the MA–4 rocket.[44]

### Training Primates and Men

For the all-important task of checking out the environmental control system on a long-duration flight, a chimpanzee was chosen to "stand in" for man. As in the preparation for Ham's suborbital mission on MR–2, two colonies of chimps traveled to the Cape about three weeks before the flight date. Again the military handlers from Holloman Air Force Base separated the colonies to prevent cross-infection. Training involved restraining the animals in a pressurized flight couch, with biosensors attached to their bodies at various points. And psychomotor training that had been started in New Mexico was continued at the Cape so that the animals' proficiency would not deteriorate.[45]

On October 29, 1961, three chimps and 12 medical specialists moved into their Cape quarters to join two other simians and eight persons already in flight preparation status. The name given to "Enos," the animal selected as the flight test subject, in Greek or Hebrew means "man," and the training and flight performance recorded by this chimpanzee proved the sobriquet to be well chosen. Captain Jerry Fineg, chief veterinarian for the mission, described Enos as "quite a cool guy and not the performing type at all." This "immigrant" from the French Cameroons had none of the tendencies of his circus-trained counterparts. Enos' backup "pilots," listed in order of their flight readiness ability, were "Duane," named for Duane Mitch, a veterinarian; "Jim," named for Major James Cook, of the same profession; "Rocky," named for a well-known pugilist (Graziano) because of his cauliflowered ear and pugnacious spirit; and "Ham," the astrochimp veteran. The ratings were made by Fineg and another Air Force officer Marvin Grunzke. Fineg later learned that when these same chimps had gone through their earlier launch and reentry training on the centrifuge at the University of Southern California, they had been rated in the same order.[46]

The psychomotor equipment used by Enos on the MA–5 mission was more complicated than that operated by Ham during the Mercury-Redstone 2 suborbital flight. Housed in the cover of his pressurized couch, Enos' package was rigged to present a four-problem cycle. The first would last for about 12 minutes, and the second followed six minutes of rest. The routine would proceed until the

cycle was completed, then the four problems would be repeated until the mission ended. Problem one would offer right- and left-hand levers that Enos could use to turn off lights, avoiding a mild shock in the left foot (the same as for Ham). The second problem planned was a delayed-response experiment. Twenty seconds after a green light would appear on the panel, Enos would have to press a lever to receive a drink of water. Although there would be no penalty for his failure to respond, if the chimpanzee should pull the lever too early the problem would simply recycle and he would receive nothing. The third, a fixed-ratio problem, would involve pulling a lever exactly 50 times to receive a banana pellet. This would also be voluntary and without penalty. Chimpanzee intelligence would be tested in the fourth. Three symbols—circles, triangles, and squares—would appear in various two-of-a-kind combinations, with the task being to pull a lever under the odd symbol to avoid a mild shock. Lack of response during rest periods would give the indication that the animal was well oriented to his spacecraft environment.[47]

Planning for this second trial of the Mercury worldwide tracking network was elaborate. Supporting the MA–5 mission were 18 stations, plus the Goddard Space Flight Center and the Mercury Control Center. Goddard and the Control Center furnished computer support and management of the overall operation, respectively.

| *Station* | *Type* |
|---|---|
| Mercury Control Center | Launch |
| Cape Canaveral (AMR) | Launch |
| Grand Bahama Island (AMR) | Downrange tracking |
| Grand Turk | Downrange tracking |
| Bermuda | Computer |
| Atlantic Ocean Ship | Remote tracking |
| Canary Islands | Remote tracking |
| Kano, Nigeria | Remote tracking |
| Zanzibar, Africa | Remote tracking |
| Indian Ocean Ship | Remote tracking |
| Muchea, Australia | Command |
| Woomera, Australia | Remote tracking |
| Canton Island | Remote tracking |
| Kauai, Hawaii | Command |
| Point Arguello, California | Command |
| Guaymas, Mexico | Command |
| White Sands, New Mexico | Remote tracking |
| Corpus Christi, Texas | Remote tracking |
| Eglin Air Force Base, Florida | Remote tracking |
| Goddard Space Flight Center, Maryland | Computing and communications |

With the exception of White Sands, all stations would receive "real time" telemetry data, consisting of magnetic tape recordings, Sanborn recorder displays, meter displays, and clock displays. The overall operation of this network was a vast cooperative undertaking of the Department of Defense, NASA, and industry.[48]

**MA–5**
**Nov. 29, 1961**



*Enos in his couch prior to launch.*



*Enos returns to the Cape following his space flight.*

Seventy-three key people assigned to the various stations received their final mission briefing on October 23. Once again the tracking teams included several Mercury astronauts. Shepard was assigned to Bermuda, Schirra to Australia, Slayton to Guaymas, and Cooper to Point Arguello, while at the Cape, Carpenter had a station in the blockhouse, Grissom was the capsule communicator in the Mercury Control Center, and Glenn served as backup capsule communicator in the center.[49]

### Chimpanzee into Orbit

By mid-October, reported George Low to NASA Headquarters, problems with capsule No. 9 and booster No. 93–D had forced STG to delay the launch from November 7 to November 14. On November 11, however, after the preflight checkout crew found a hydrogen peroxide leak in the fuel line of the capsule manual control system, the earliest possible launch date slipped to November 29.[50] Although NASA did not comment officially on the effect of the delay, chances for a manned orbital mission in 1961 now were dim.[51]

On November 28, 1961, an 11½-hour launch preparation count began for MA–5. The count stopped at T minus 390 minutes, to be resumed the next day. Some 11 hours before the launch, Enos, the 39-pound chimpanzee, underwent his final physical examination, stood still as his medical sensors were taped on, allowed himself to be secured in the specially constructed primate couch, and rode in the transfer van to the gantry. About 5 hours before launch the couch

was inserted in the spacecraft. Thereafter Enos' condition was monitored by lines connected to his couch in the Mercury capsule and by radio telemetry. He was relaxed during countdown. His temperature ranged from 97.8 to 98.4 degrees, normal for the suit inlet temperature of about 65 degrees; his respiration averaged 14; and his pulse rate was 94. The only time Enos displayed agitation was when he was roused by the opening of the hatch during a countdown hold caused by a telemetry link failure at T minus 30 minutes. The gantry was hauled back to the spacecraft, the hatch was opened, and an off-and-on switch was correctly positioned. This hold lasted 85 minutes. Some members in the control center joked that Enos had turned the switch off because he had talked to Ham and did not want to go.[52]

In the Mercury Control Center the flight control monitors had manned their stations and were busily checking out their consoles. Tecwyn Roberts, serving as flight dynamics officer, noted the intermittent problems cropping up in the data-gathering and translating computers. A faulty transistor in the direct data receiver caused one hold, and when the replacement was also faulty, several more minutes were lost in repairing the computer. Morton Schler, the capsule environment monitor, reported that the environmental control system was working smoothly. The Freon flow rate, he reported, leveled at a comfortable 20 pounds per hour in the prelaunch period. From the oxygen partial-pressure transducer some erratic readings proved erroneous; Mercury Control teletyped the tracking stations to discount these readings as the spacecraft passed over.[53]

Holds during the countdown amounted to almost 2 hours and 38 minutes. Shortly after the hatch was bolted at T minus 90 minutes, the technicians discovered that they had failed to install some hatch cover heat insulation material. They took a little more than an hour to correct this oversight. Then, at T minus 30 minutes, the discovery of an improperly positioned switch necessitated the 85-minute hatch-opening hold. And finally, at T minus 15 minutes, a 4-minute hold was called to correct a data-link problem between Mercury Control and the General Electric ground command guidance equipment.

Walter Williams, the mission director, listened as the various difficulties arose and became somewhat agitated at the chain of events. Although his usual position during such times was at a console in the mission control center, he left the building and quickly drove the distance to pad 14 to personally express his expectations that things would proceed in a more orderly manner. As a member of Convair later said, "Williams was a master in imparting a need for orderly urgency."

Despite these holds, weather conditions remained favorable. Only a few thin cirrus clouds hung in the sky, visibility was 10 miles, and the surface wind velocity was at a moderate 11 miles per hour from the northwest. In the landing area the weather was even better.[54]

The Goddard computers received the liftoff signal 13 seconds before the booster actually rose from the pad, an error apparently caused by feedback between two recorders. Nor was this the last incorrect signal. The Goddard computers

registered sustainer engine cutoff twice before that event happened, once shortly after liftoff and again two minutes after launch. In each case the Mercury Control Center had to switch to override the signal until the panel indicator cleared.[55] Liftoff came at 10:08 a.m. The powered phase of the flight went well, although there were minor discrepancies. Between liftoff and staging, the horizon-scanner signal was lost briefly. All spacecraft systems nevertheless appeared to be working normally, with the guidance system of the Atlas keeping the booster on an almost perfect insertion trajectory. Guidance system noise was only about half that recorded during MA–4, and vehicular vibration also was much lower. Four and a half minutes after launch, Christopher C. Kraft, Jr., unhesitatingly made the go-for-orbit decision. At sustainer engine cutoff, the velocity, flight angle, and altitude were nearly perfect. The Atlas hurled the spacecraft into an orbit with a perigee of about 99 miles and an apogee of 147 miles, .5 and 5.4 miles low, respectively.[56]

Spacecraft and booster separation occurred precisely as planned, while the turnaround maneuver took less than 30 seconds. The capsule's position excursions were very slight, which contrasted sharply with the erratic turnaround of MA–4. The spacecraft quickly dropped into its 34-degree orbit mode and began streaking over the oceans and continents. Of the 61.5 pounds of control fuel aboard, turnaround and damping had consumed 6 pounds, as opposed to 9.5 for MA–4. From that point and on through the first orbit the thrusters used only 1.5 pounds to maintain a correct position, with the automatic stabilization and control system functioning perfectly.

The environmental control system and the tracking and communications network performed in a satisfactory fashion. On this mission, for the first time, the primary and secondary oxygen bottles were pressurized at 7500 pounds per square inch (the design specification) rather than at 3000, as on previous flights. A functioning water separator also was used for the first time. Each tracking station's range on the ultra-high-frequency band lasted for about six minutes; on high frequency, overlap communications between stations were similar to that experienced during MA–4. The Goddard computers received valid telemetry data from all stations except Woomera, but there were instances when communications were momentarily lost at particular stations. Just before retrofire, for example, Point Arguello, the site giving the firing command, lost contact with the Cape. In each instance, as Walter Williams would point out at the postflight press conference, communications were reestablished whenever that particular station was needed.[57]

Enos, the orbiting chimpanzee, fared well. He withstood a peak of 6.8 g during booster-engine acceleration and 7.6 g with the rush of the sustainer engine. He had been performing his lever-pulling duties for some two minutes before the Atlas roared and rose from the pad. During his two orbits he made 29 pulls (divided among four sessions) on the continuous-avoidance and discrete-avoidance levers, receiving only one shock in each category. On his second problem, which

required at least a 20-second delayed response to receive a drink of water, his average delay was about 33.8 seconds. For these labors he was rewarded with a total of 47 measures of water, or about a pint during the three-hour mission. For the fixed-ratio task, problem three, Enos pumped his lever and received 13 banana pellets during his four opportunities. On the first session of problem Four, Enos was correct for 18 out of 28 symbol presentations (64.2 percent), thus receiving 10 shocks as a result of his miscues. On the second session of problem four, however, the center lever malfunctioned, causing shocks even if he pulled the correct lever. He received 36 and 43 successive shocks on the third and fourth sessions, respectively, because a manmade device had failed. The shocked and frustrated chimpanzee nevertheless kept pulling the levers. As he was also trained to do, Enos remained at rest during the six-minute intervals between problems.[58]

Near the end of the first orbit, the tracking monitors noted that the capsule clock was about 18 seconds too fast and as it passed over the Cape a corrective command was dispatched to and accepted by the clock. At that time the Mercury Control Center display panels indicated that all spacecraft systems were in good order. Suddenly the Atlantic tracking ship reported that inverter temperatures were rising. The Canary Island trackers confirmed the environmental control system malfunction. Since abnormal heating had occurred on earlier flights and the inverters had continued working or had switched to standby, there was no alarm among members at Mercury Control. Then, across the world from the Cape, Muchea, Australia, detected high thruster signals and capsule motion excursions, although other data indicated that the 34-degree orbit mode was being maintained. The Woomera, Australia, tracking station failed to confirm this report, and it was discounted.[59]

By the time the MA–5 capsule reached the vicinity of the Canton Island station, the operations team realized that the attitude control system was allowing the vehicle to go out of its proper orbital mode. A metal chip in a fuel supply line (the postflight inspection would reveal) had cut off the propellant flow to one of the clockwise roll thrusters. This inactive thruster allowed the spacecraft to drift minus 30 degrees from its normal attitude, at which point the automatic stabilization and control system brought the spacecraft to zero in a normal roll-turn maneuver. Then the spacecraft swung briefly back into the nominal 34-degree orbital attitude, and the sequence started again. The spacecraft repeated this process of drift and correction nine times before retrofire and once more between retrofire and the receipt of the .05-g light telemetry signal. The still-active thrusters used about 9.5 pounds of control fuel working to keep the capsule properly aligned. Each loss of orbit mode cost a little over a pound of fuel compared with a first-orbit expenditure of only 1.5 pounds.[60]

The cooling equipment in the environmental control system also began to give trouble during the second orbit. Between the Canary Islands and Kano, the suit circuit temperature rose rapidly from 65 to 80 degrees, indicating a freezing condition in the heat exchanger. As water in the felt evaporator pad of the

exchanger turned to ice, Enos' body temperature climbed to 99, then to 100 degrees. The medical observers began to worry, especially about the chimp's ability to handle his psychomotor test problems. Then, at 100.5 degrees, his body temperature appeared to stabilize, suggesting that the environmental system was ceasing to overheat. Their fears relieved, the physicians felt that the mission could continue. Although the cooling system had seemed to correct itself, Kraft, the flight director, later remarked that a deicing unit should be added to warm the troublesome unit, which had also caused a freeze-up on MA–4.[61] Although the medical monitors were willing to allow the mission to proceed through its scheduled third pass around the world, the operations team believed that the problem of the spacecraft's erratic attitude was too grave to live with. The engineers felt that there simply was not enough attitude fuel left to complete the circuit and then go through the reentry phase, in which, even under normal circumstances, fuel usage would be high.

After the attitude aberrations were first noted, Kraft had alerted the tracking unit in Hawaii for a possible clock change to initiate retrofire during the second orbit. Then he decided to continue the flight toward California and notified Gordon Cooper at Point Arguello that that station might have to initiate a ground command for retrofire. Meanwhile, the capsule continued to drift and swing in and out of the orbital mode, demonstrating that the attitude control system, unlike the environmental control system, would not solve its own problems. Twelve seconds before the retrofire point was reached for the normal second-orbit primary recovery point, Kraft decided to bring Enos back to Earth. Arnold Aldrich, MSC's chief flight controller at Point Arguello, correctly executed the command.[62]

With the exception of the one repeated variation in attitude position, caused by the dead roll thruster, reentry went according to plan. The destroyers *Stormes* and *Compton* and a P5M airplane began preparing for spacecraft retrieval in Station 8, the predicted impact point. Three hours and 13 minutes after launch and about nine minutes from water impact, the P5M spotted the descending spacecraft at an altitude of about 5000 feet and radioed the *Stormes* and the *Compton,* 30 miles away. All spacecraft recovery aids except the sarah beacon functioned properly. During the spacecraft's descent, the airplane circled and reported landing events, then remained in the area until the *Stormes* arrived, an hour and 15 minutes after the landing, and hauled Enos and his spacecraft aboard. Shortly thereafter the hatch was explosively released from outside the capsule by a pull on its lanyard, causing the chimp's "picture" window to crack.[63]

Aboard the *Stormes* and later at Cape Canaveral, Manned Spacecraft Center and McDonnell engineers gave the capsule the usual close scrutiny and happily found that it had held up well. Except for a slight discoloration caused by aerodynamic heating, the exterior showed no buckling or warping. The interior was in good shape, too, although the inspectors did find a small amount of salt water. Activation of the explosive hatch caused minor damage in the form

of the cracked window, several bolts pulled from the skin, and a slight buckle. Thermodynamic effects on the ablation heatshield had produced several radial and circular cracks, none of which had been severe enough to threaten the capsule's structural integrity. The center plug of the heatshield was missing (it had only worked loose on MA–4), but close inspection of the opening showed that the plug had evidently been in place during reentry. Condition of the impact bag, which had survived its first orbital test, was fairly good, although several straps were broken and others were severely bent. Again the plastic bulkhead was pierced, probably by the heatshield, and the honeycomb material was crushed in several places. There was no damage to the tubing or wiring in this area.[64]

At the Cape postflight press conference the leaders of Project Mercury revealed no regrets over missing a third orbit. They seemed to regard the reprogramming operation, conducted in the middle of the mission, as a satisfying technical accomplishment. In view of the decisiveness with which the various potentially critical difficulties had been overcome or circumvented, MA–5 had to be termed an excellent operation, one that had achieved most of its objectives and that would become a milestone on the road into the unknown.

Enos had been weightless for 181 minutes and had performed his psychomotor duties with aplomb. Operations director Williams felt that an astronaut riding in the MA–5 spacecraft could have made the necessary corrections in flight to complete the three-orbit mission normally. On the spacecraft attitude control problem, for example, a man could simply have switched from automatic to manual mode, he said. At the same time, Williams was pleased that the automatic systems had worked well for over two hours. Equally significant, the vast network of NASA, military, and industry personnel had performed like veterans during the emergency. The spacecraft had reentered and landed without handing the Navy any unexpected recovery problems.

## Now a Man in Orbit?

The press corps at the usual postflight press conference listened courteously to this technical postmortem, but their main concern was whether another test mission would be flown before a manned orbital flight. Williams and Gilruth cautiously replied that first the MA–5 data would have to be thoroughly evaluated. Then the reporters wanted to know who had been selected to make Mercury's first manned orbital flight. Gilruth was ready for that one; he announced the team members for the next two missions. John H. Glenn was the selected prime pilot for the first mission, with M. Scott Carpenter as his backup. Donald K. Slayton and Walter M. Schirra were pilot and backup, respectively, for the second mission.[65] This announcement represented a considerable change from the tighter news policy regarding crew selection that had prevailed in suborbital days.

Meanwhile Enos had his moment. After the urbane anthropoid came

aboard the *Stormes,* he ate two oranges and two apples, his first fresh food since he had gone on a low-residue pellet diet. The destroyer dropped Enos at the Kindley Air Force Base hospital in Bermuda, where Jerry Fineg took over. The chimp was walked in the corridors and appeared to be in good shape. His body temperature was 97.6 degrees; his respiratory rate was 16; and his pulse was 100. Apparently reentry, reaching a peak of 7.8 g, had not hurt him. His composure at his "press conference" surprised the correspondents. One reporter remarked that Enos, unlike Ham, did not become "unhinged" with the popping of the flash bulbs. On December 1, Enos reached the Cape for another round of physicals, and a week later he departed for his home station at Holloman, and well-deserved retirement.[66]

Enos' fame was short-lived. Public attention now turned to the supposedly imminent American manned orbital flight, although there still was no assurance that a spacecraft would next carry a man. Speculation mounted when Atlas 109–D was hauled into the Cape on the night of November 30. Newsmen immediately gathered around B. G. MacNabb, the Convair preparation chief, to ask when the checkout would start. "Tomorrow," he replied. When asked if there would be a crash effort in order to make the flight in 1961, Wil-

"We're a Little Behind the Russians and A Little Ahead of the Americans"




*A humorous view of the implications of the "monkey flights" to the space race was offered by cartoonist John Fischetti of the Newspaper Enterprise Association.*

liams said that three shifts were working a 168-hour week (all the hours possible), and that no special pressure would be applied. None of these statements dampened speculation by the press early in December. Signs, rumors, and portents cropped up daily. One correspondent, for example, noted that John Glenn had moved into special quarters at the Cape, adding that NASA had requested Atlantic Missile Range support beginning on December 20 and continuing to year's end.[67]

If NASA had ever been involved in a drive to put an American in orbit in the year of the Vostoks, that effort halted on December 7, the 20th anniversary of the Pearl Harbor attack. Almost casually Gilruth and Williams announced that the flight was now scheduled for early 1962. The decision, said MSC officials, had been influenced by "minor problems dealing with the cooling system and positioning devices in the Mercury capsule." The official press release did state that NASA considered the spacecraft, its systems, and the tracking network qualified for manned flight. It had been apparent to many NASA officials for some time that the manned orbital launch might have to be postponed until 1962. George Low, at NASA Headquarters, had recognized the probability soon after mid-October, when he wrote, "The pad conversion time between MA–5 and MA–6 is exceedingly short if MA–6 is to remain on schedule." On schedule meant December 19.

Hugh L. Dryden summed up his philosophy regarding adherence to schedules for manned flight when he said, "You like to have a man go with everything just as near perfect as possible. This business is risky. You can't avoid this, but you can take all the precautions you know about."[68]

Although there was regret that this country did not get a man into orbit before the Soviets, or at least in the same year, 1961 had recorded substantial progress toward making the United States a spacefaring nation. In contrast with the atmosphere of uneasiness marking the end of 1960, the Manned Spacecraft Center engineers now knew that they were on the brink on fulfilling Project Mercury's basic objectives. The rehearsals were over.

# XIII

## Mercury Mission Accomplished

PROSPECTS looked bright to the managers of Project Mercury at the beginning of 1962. In store was Mercury-Atlas 6, scheduled as a manned orbital flight and viewed by some as a salvage operation for America's space prestige. If one of its citizens, Marine pilot John Glenn, journeyed successfully through space on a multi-orbit global mission, the United States would at least begin matching the pace set by the Soviet Union. Although a 3-orbit trek would by no means equal the 17-orbit, day-long voyage of Gherman S. Titov, the imminence of the mission had helped to allay national uneasiness somewhat. The notion that the manned orbital launch should be made in 1961 to coincide with Russian feats in the history books subsided with the end of the old year; 1962 was now here. Whatever regrets the American people had harbored over the numerous delays in Project Mercury, they seemed reconciled to schedule slippages if safety demanded them.

But the new year was barely three days old when the news media learned that the announced launch date of January 16 had been postponed until January 23, at the earliest, because of technical problems in the booster fuel tanks. With each succeeding delay, and there would be several more, journalists and Congressmen became a little more critical and fidgety. Once again, as on several previous occasions, the press spoke of the "space gap," and doubts were raised by some writers that the Mercury undertaking would ever succeed. A senior member of the House Committee on Science and Astronautics, Republican James G. Fulton of Pennsylvania, apparently subscribed to this feeling when he remarked, after viewing a January 27 MA–6 launch attempt, that the Mercury spacecraft and Atlas booster could be described as "a Rube Goldberg device on top of a plumber's nightmare." President Kennedy disclosed at a news conference on February 14 that he too shared the general disappointment voiced about delays in the program, but he added that the decision to go or not to go should be left to the "group who are making the judgment." Moreover, he reaffirmed his faith in the NASA Mercury team: "I'm going to follow their judgment, even though we've had bad luck." [1]

Statements issued by the Manned Spacecraft Center's operations team after each postponement of the MA–6 mission were terse and technical, and their frankness in reporting the reasons for these delays prompted some favorable news comment. The *Wall Street Journal* commended NASA for its open information policy, and pointed out that anything but "Candor at Canaveral" could only hurt the "national image." In response to their persistent and sometimes annoying questions, reporters were quietly told that this mission had been in the planning processes for almost three years and that a few more days' or weeks' delay was of little consequence if confidence in its success could be raised another notch. This acceptance of the situation by the Cape launch crew and operations team stemmed from the program's composite flight test experience. John Glenn, knowing all of this, enjoined the press representatives covering the event not to worry: [2]

> This mission has been in preparation for a long time. I can't get particularly shook up about a couple of days' delay. As a matter of fact, I'm so happy to have been chosen to be the pilot for this mission that I'm not about to get panicky over these delays. I learned very early in the flight-test business that you have to control your emotions—you don't let these things throw you or affect your ability to perform the mission.

The Mercury team alone knew what had to be right to make it go.

Back in October 1959, the MA–6 flight, possibly carrying a chimpanzee in spacecraft No. 18, had been scheduled for launch in January 1961. But the fortunes or misfortunes of manufacture and the ensuing flight test program forced many schedule slippages, redesignation of flight order, and capsule configuration changes to meet altered test objectives. According to an April 1960 chart, the first manned orbital attempt (originally MA–7) was slated for a May 1961 launch. Six months later the planners moved the target date for this mission to July, and after a similar interval they foresaw October as the likely launch date. NASA Headquarters' approval of the proposal to add one-day missions to the Mercury flight series required further schedule alterations. Several spacecraft had to be modified for the flights of longer duration. Spacecraft No. 13 was allocated to the MA–6 mission, replacing No. 18, which now was entered into the modification cycle. In spite of all this shuffling, as late as October 1961 the program managers held hopefully to an anticipated manned orbital liftoff within 1961. MA–6, instead of MA–7, the managers indicated, would carry the first astronaut into orbit, providing the MA–5 chimpanzee flight succeeded in November.[3]

A host of manufacturing changes had delayed the progress of spacecraft No. 13 as it traveled through the McDonnell production and checkout line. Number 13, beginning to take form in May 1960, also met with the usual fabrication problems its predecessors had faced during assembly. On October 10, for example, McDonnell reported to the Space Task Group that a shortage of environmental control system components had completely halted work on the cap-

sule's interior. At the end of January 1961, however, the company had started a three-month test shakedown of the vehicle. Shortly after the completion of this work the failure of the MA–3 mission on April 25 had forced a rearrangement of spacecraft allocations, and McDonnell had been told by the NASA planners to redesign No. 13 for the initial manned orbital mission. The factory finished and delivered the spacecraft to the Cape on August 27. Four months later, after a thorough checkout by the Manned Spacecraft Center's (formerly Space Task Group) Cape team, on January 2, 1962, it was mated to its launch vehicle, Atlas 109–D.[4]

These had been some of the trials that made planning and scheduling difficult occupations, especially in a program that had been so often under national scrutiny. Therefore, the successive MA–6 launching delays logged in the early days of 1962 simply were noted and accepted, and the planners met to decide when they could be ready to try again.

## Preparing a Man to Orbit

Of course, hardware was only part of the problem of readying MA–6. What about the second half of the "spacecraft-man" combination? Would the man be just a passenger-observer or a participating system? By mid-September 1961, Robert B. Voas, the astronauts' training officer, had drawn up a number of basic specifications concerning the pilot's duties in MA–6 in answer to questions of this sort. If some part of the automatic attitude control system should fail, for example, the pilot would need to control spacecraft attitude using the manual system. Or if displayed information on the spacecraft's attitude position should malfunction, the pilot would have to take over and rely on his visual abilities for position reckoning by external references. Voas had studied high-altitude photographs of the MA–4 flight and he knew that on the sunlit side of Earth the horizon should quickly provide an excellent capsule attitude reference, but the nightside might present problems unless there was bright moonlight. Possibly known stars could serve as attitude reference points, he theorized. Voas also felt that a comparison of window and periscope reference was needed.[5]

To measure man's potential as a spatial navigator, Voas wanted the astronaut to look for the smallest detectable landmark, to estimate the effects of weather conditions on visibility, and to judge precisely the occultation of the stars by Earth's atmosphere. Theoretically, from the vantage point of the orbital flight trajectory an astronaut should see about a 900-mile arc of the horizon. He should be able to determine how much of this was effective horizon in terms of his ability to recognize a landmark with the unaided eye. One important facet of any later space exploration, Voas said, would be man's visual acuity in estimating spatial depth and distance; tracking an artificial object in a nearly identical orbit during a Mercury circumnavigation would partially test this ability. The spent Atlas tankage trailing the capsule should offer an excellent opportunity in this respect.

Ever since the Soviet reports of Gherman Titov's sensations of dizziness and nausea caused by his head and body movements, some aeromedical specialists had worried that perhaps the prolonged absence of gravitational stress did adversely affect a space passenger or pilot. Voas, considering this subject, contended that it was impossible to say whether Titov had had a purely personal aversion to weightlessness or whether men in general would have similar troubles under zero g. Neither Alan Shepard nor Virgil Grissom had experienced vertigo during the two Mercury suborbital flights. Voas felt that if disorientation and nausea were in fact products of longer durations of weightlessness, as some physicians and physiologists believed, the symptoms could be remedied through preflight training, proper flight procedures, or, if necessary, by drugs.

Voas acquainted the astronauts with the probable effects of weightlessness on their sensory organs. The otoliths, the ear's angular accelerometers, should not be affected, he said. Muscle and skin sensory functions should be affected only slightly, but those muscles sensing the amount of gravity would lose their acuity completely. By and large, the general diminution of sensory perception accompanying space flight should be overcome by the astronaut's eyes and his memory. To test his theories, Voas prescribed an experiment to be conducted on the dark side of Earth. The pilot would touch certain panel dials with his eyes open and then with his eyes closed, after moving his head quickly to the right, left, and forward. Gordon Cooper expressed qualms felt by several people over Voas' "blind flying" test when he remarked, "You shouldn't be reaching over on this panel with your eyes shut."

Other tasks planned by Voas included taking pictures through the window and periscope with a hand-held camera, describing the cloud cover on the day side, and looking for lightning in squall lines as requested by the United States Weather Bureau. On the night side the pilot should repeat those tasks and observe the aurora and luminescence of Earth's clouds. Finally, he should scan the star fields, the Milky Way, and note the size and appearance of the Moon as well as describe a moonset.[6]

The September study by Voas included the initial efforts of the Space Task Group to foster a scientific inroad into the manned space flight program. After distributing his paper among the astronauts and receiving favorable comment from several, Voas then sought the assistance of NASA Headquarters to obtain a broader base for possible astronaut activities in space from the various scientific disciplines that were available. Homer E. Newell and Nancy G. Roman of that organization reacted by directing the formation of an ad hoc committee for astronomical tasks for the Mercury pilots, assigning Jocelyn R. Gill as the committee chairman. This group was an offshoot of the formal Astronomy Subcommittee, a part of NASA's Space Sciences Steering Committee.[7]

As a beginning Gill and Voas attended a meeting of the Astronomy Subcommittee held at the Grumman Aircraft Engineering Corporation, Bethpage, New York, on October 30–31, 1961. Voas reviewed the abilities of the astronauts

to assume some additional tasks, such as observations of astronomical phenomena. He also cautioned that any integration of scientific equipment inside the spacecraft would have to be severely restricted in weight. The Astronomy Subcommittee discussed the possibilities and then suggested 10 tasks that an astronaut might accomplish. A few of these were: observe the night airglow as to its intensity and structure, look for comets before sunset and after dawn, note the frequency of meteor flashes, look for the aurora and describe its intensity, sketch the zodiacal light relative to the star background, and observe the size and position relative to the star background of the gegenschein.[8]

Besides generally acquainting the Mercury astronauts with the spatial environment, their possible reactions, and what they might accomplish in the way of operations and scientific observations, Voas also had pressed forward with a plan for a specific training program to prepare the crewmen to operate and manage the spacecraft systems on orbital missions. He first compiled a list of proposed training activities, and then he called a meeting at Langley on September 26 to discuss his report. The STG officers present adopted the training proposal, which became a formal working paper on October 13. With slight subsequent amendments, this working paper, No. 206, spelled out the astronaut training and preparation procedures that would be followed for the rest of the Mercury program.[9]

The first stated prerequisite for the astronaut, as formulated by Raymond G. Zedekar of STG, was a thorough familiarity with the spacecraft and all its systems. He must know every mission detail, including every flight and ground rule; he would be expected to demonstrate peak performance in every task during the flight; and his skills must include making failure diagnoses and taking the proper corrective action.

Preparing the pilot for his role during an orbital mission, the astronaut training personnel obviously could draw heavily on Shepard's and Grissom's suborbital experiences. The nine separate checkouts of the spacecraft after it arrived at the Cape, they felt, would provide excellent familiarization and systems training for the prime pilot and his alternate, who would be assigned to take turns in the capsule's contour couch. Then, if any modifications to the hardware or change in methods should become necessary, either man would be fully prepared to give valuable advice as well as to learn how the component change or new procedure would affect the mission. But by all accounts, as particularly ascribed to by the Mercury suborbital pilots, the best training sesssions for practicing both normal and abnormal flight conditions in the Mercury program were those held in the procedures trainer. There all phases of a mission—prelaunch, countdown, launch, orbit, reentry, recovery, and emergency—could be simulated. The training planners decided that at least 30 hours of practice would be scheduled in this McDonnell-made trainer. On some occasions the simulation called for hooking the trainer in with the Mercury Control Center and the Bermuda tracking site, an exercise that also would help the flight controllers check, promulgate, or practice their communications and control procedures.

Voas and his colleagues scheduled numerous other training activities that would supposedly hone the astronauts to a fine edge. One such plan called for the pilot or his designated stand-in to attend the spacecraft scheduling meetings, operational planning sessions, and booster, spacecraft, and mission reviews. After the spacecraft had been mated with the booster, the astronaut would have a key role in the capsule systems test, sequential and abort exercises, and the simulated flight that accompanied each countdown launch simulation. With the astronaut sitting in the spacecraft, all countdown checks would be run up to the point of hatch installation. Voas' training document stipulated that even the exercise of slipping the pilot into his capsule should be practiced until the insertion crew had it down perfectly. Besides all this work at the Cape, preflight trips were planned to the Morehead Planetarium in North Carolina, so that the astronaut and his backup pilot could fix star patterns in their minds as an aid to their orbital celestial observations. To obtain a familiarity with angular motion, they would attend sessions in the Pensacola Naval Air Station's "rotating room" and on the human disorientation device. Egress training, the value of which Grissom vouched for after his harrowing recovery, was scheduled on the open water in the Atlantic. Finally, there were Morse code instruction, map study, and briefings by the Weather Bureau support team on observation procedures.[10]

All these varied tasks had to be scheduled in logical progression to bring about a status of "flight readiness." The original training directive specified that an intensive training program for an upcoming flight should begin with a comprehensive study of all capsule instrumentation about 81 days before the launch was scheduled. Nine days later, after the astronaut and his alternate had memorized everything they could about the capsule instrument panel, they would start spending at least three hours per week in the procedures trainer, making brief excursions to Langley for sessions on the air-lubricated, free-axis (ALFA) trainer. In the procedures trainer they would go through specific mission profiles. These included a normal one-orbit mission, lasting about 90 minutes, with the astronaut in casual clothes; five-hour sessions simulating three orbits, with the astronaut wearing a pressure suit on some occasions; and 30-minute abort simulations, including such hazards as the failure of the retropackage to jettison, failure of the spacecraft's main batteries shortly after orbital insertion, and many other malfunctions covering every conceivable contingency that the training officers could devise.[11]

By December 1961, after Glenn and Carpenter had been publicly named for the Mercury-Atlas 6 mission, training plans were expanded to include their medical evaluations. For the altitude chamber simulated flight conducted about 45 to 60 days before the anticipated launch, Glenn was examined, fitted with biosensors, suited, pressure-checked, and then loaded into the transfer van and medically observed during the trip to the altitude test chamber. After he seated himself in the couch, his biosensor data were checked, his electrocardiogram leads were monitored, and the newly fabricated blood pressure equipment was exercised. Also there was a checkout of the spacecraft's environmental control system.[12]



*Glenn performs simulated flight in the procedures trainer; Robert B. Voas looks on during the training session.*




*Glenn undergoes disorientation test.*

**MA–6**
**Preflight**






*Carpenter practices egress from the neck of Glenn's spacecraft.*

*Glenn takes time in the pad white room to pose with Thomas J. O'Malley of General Dynamics and Paul C. Donnelly of STG.*

Jocelyn Gill also began planning the scientific aspects that Glenn might attend to while he was in orbit, when she called the first meeting of the ad hoc committee in Washington on December 1, 1961. William K. Douglas, Voas, and John J. Van Bockel attended from the Manned Spacecraft Center. The main purpose of this gathering was to adjust the suggestions emanating from the earlier meeting of the Astronomy Subcommittee into a workable order to provide the astronauts with as much background as possible of what they might expect to see in space. The first piece of equipment for scientific purposes aboard the spacecraft discussed was a small filter planned for use in studying the irregularities of the night-sky illumination and aurorae. For later missions an ultraviolet camera was suggested for possible use in photographing the stellar spectra.[13]

Some eight days later Glenn, Carpenter, and Schirra accompanied Voas and Douglas to a second meeting called by Gill. Point by point the requested astronomical observations were explained to the three astronauts. Because of their evident interest, Gill was of the opinion that such briefings, perhaps with even more detailed information, should be provided at intervals as well as just before flight time.[14]

During the month before the MA–6 mission, Glenn underwent at the launch site a realistic test termed "Pad Rehearsal No. 1." This exercise started with biosensor and suiting-up preparations at the hangar, transportation to the pad, and insertion of the astronaut into the spacecraft. Both the blockhouse and the Mercury Control Center were tied into and participated in this exercise. Several days later this operation was carried out again, and this time the gantry was pulled away to make conditions more realistic. Then about three days before the scheduled flight, after he had already begun his low-residue diet, Glenn went through a simulated mission encompassing the entire flight plan.

Other preflight medical activities included a complete physical examination two days before the anticipated launch. The Mercury physicians issued Glenn a number of medications for his survival pack, including morphine for pain, mephentermine sulfate for shock, benzylamine hydrochloride for motion sickness, and racemic amphetamine sulfate (a common pep pill) for a stimulant. Radiation-measuring film packs were tucked inside the spacecraft.[15]

Glenn and Carpenter had completed most of their preflight training program by the end of January, but the continuing delay of the MA–6 launch forced them to go on with their crowded routine. Glenn spent 25 hours and 25 minutes in the spacecraft during the hangar and altitude test chamber checks and uncounted hours on the pad after the launch rocket and spacecraft were mated. On the procedures trainer between December 13, 1961, and February 17, 1962, he logged 59 hours and 45 minutes (far beyond the 30 required by the training directive) and worked through 70 simulated missions in the process, reacting to some 189 simulated system failures. Glenn and Carpenter, along with Donald Slayton and Walter Schirra, already picked for MA–7, participated in a two-day (December 11 and 13, 1961) recovery exercise on the Back River near Langley Air Force

Base, Virginia, easily making both top and side hatch exits. Later Glenn and Carpenter, wearing life vests, carried out a survival equipment exercise off the beach at Cape Canaveral.[16]

Not only the pilots but many others were training for the MA–6 mission. On January 15, 16, and 17, 1962, recovery team swimmers practiced jumping from helicopters and placing the new auxiliary flotation collar around a boilerplate capsule. The flight controllers who were to deploy to the remote tracking sites got their final briefing on January 3 and left for their respective stations, where they engaged in seven rather extensive network exercises. Mercury Control, Goddard, and the Bermuda site conducted tests to check the Control Center-Bermuda abort command sequence. On January 25, Eugene F. Kranz reported to Christopher C. Kraft, the flight director, that the network team was at its peak condition. He feared that motivation and performance might decline if the flight continued to be delayed.[17]

Although this was to be the first manned orbital flight in Project Mercury, earlier flights set many precedents in the planning process for such items as recovery requirements, mission rules, and test objectives, and consequently the mission planning for MA–6 was almost routine. The launch azimuth heading was to be the same that Enos had followed into orbit riding MA–5; the recovery forces, now thoroughly seasoned, although somewhat larger than for MA–5, were stationed to cover essentially the same landing areas; ignition procedures and range rules for the launch were about the same as on previous Mercury-Atlas missions.[18]

### Buildup for the Space Offensive

Again NASA invited the world's news media to send representatives to cover one of its launches. On December 5, 1961, Headquarters informed newspaper and magazine editors that NASA was planning to accommodate up to 400 accredited reporters. No exact flight date was mentioned, but the press was told that the launch would occur "either late this year or early the next." [19] All hopes for a 1961 shot were dashed two days later when NASA Headquarters announced the postponement of MA–6 until early 1962.

Work to assist the news media in covering the event had been proceeding at the Manned Spacecraft Center for some time. Several months before the MA–6 launch, its Public Affairs Office, then under the direction of Lieutenant Colonel John A. "Shorty" Powers, began preparing a "Public Information Operating Plan," giving the estimated dates on which particular phases of the mission plan would be carried out. Powers evaluated each segment of the plan and recommended to the press various training and hardware preparation activities that the reporters might be interested in covering, as well as arranging for the reporters to cover flight-day activities. News release handouts were prepared covering almost every conceivable phase of the flight, from what the pilot would have for breakfast to an intricate discussion of how a spacecraft attitude control system should work.

About five days before the anticipated launch date, Powers and his troupe established a news center at Cocoa Beach, Florida. Some of his men were assigned to pass out fact sheets, some were to record pictorial events surrounding the flight for use by the news media, some were to seek answers to the myriad technical queries posed by newsmen, and some were assigned to prepare advisories concerning mission progress status.

Correspondents accredited by NASA, many clad in colorful beach raiment, descended on the area. They avidly consumed the space agency's prepared information, interviewed key figures of the NASA-DOD-industry operations team, sunned on the beach, and pressed for more news and anecdotes after the evening meal. Some critics likened the atmosphere to that of a circus, but literally hundreds of thousands of words about every conceivable phase of the manned space program poured out for the edification of the tax-paying masses.[20] Surely in history no program that still essentially was in its research and development stage had ever been so open to the public through the eyes of the Fourth Estate.

The first "gathering on the beach" to view the MA–6 launch occurred on a cloudy Saturday morning, January 27, 1962, after bad weather had forced the launch to slip day-to-day from January 23, when the firing was first intended. The countdown ticked on but the overcast remained solid, and a general feeling swept through the crowd of faithful "bird watchers" that this still was not the day. Finally, at T minus 20 minutes Walter C. Williams, the mission director, canceled the shot. The overcast was so heavy that the necessary camera coverage of the early trajectory events would be impossible. "It was one of those days," said Williams later, "when nothing was wrong but nothing was just right either. I welcomed that overcast." [21] John Glenn had been in his spacecraft, *Friendship 7*, named in a contest by his own family, a little over five hours. The rescheduling of the launch for February 1, four days ahead, necessitated emptying and purging the Atlas of its propellants.

On January 30 the ground support crew once more began fueling Atlas 109–D. During preflight checkout, a mechanic discovered, by a routine opening of a drain plug, that there was fuel in the cavity between the structural bulkhead and an insulation bulkhead separating the fuel and oxidizer tanks. The launch vehicle team estimated that, since the insulation had to be removed, a maximum of 10 work days would be needed to correct the problem and to check out the systems. This delay would slip the launch date, and slipping the launch date caused problems for the recovery force. Some 24 ships, more than 60 aircraft, and a number of specialized units, manned by a combined total of 18,000 personnel around the world, had to consider whether they could remain at their stations for a new date that might very well slip again. When all the tallies from the widespread units were before the recovery force commander, Rear Admiral John L. Chew, February 13 seemed the earliest possible next try at MA–6.[22]

On January 31, amidst an audible groan from more than 600 news-media



*Press site 2, Cape Canaveral, in the early morning hours of January 27, 1962.* Friendship 7 *is silhouetted against gray clouds that would postpone the mission.*

representatives who had managed to become accredited, the new launch date two weeks ahead was announced. Two weeks more at the Cape was too much for most of the benumbed newsmen; the exodus from the Florida peninsula began immediately. Only the spacecraft and launch vehicle technicians were left to minister, as Walter Williams termed it, to the "sick bird." Glenn took several days off to spend some time with his family at home in Arlington, Virginia. On one occasion he crossed the Potomac River to the White House for a brief visit with President Kennedy, who asked him many semitechnical questions about plans and systems for the orbital flight.[23]

On February 9, as NASA personnel began to move back to the Cape, the weather was still foul. Evidently the newsmen felt there was little chance for a launching on the scheduled date; by the 13th only 200 had checked in at the motels in nearby Cocoa Beach. They received some grist for the journalistic mill at a press briefing arranged by NASA's Paul P. Haney and "Shorty" Powers. Robert L. Foster from McDonnell answered some questions about the spacecraft and Major Charles L. Gandy and Lieutenant Colonel Kenneth E. Grine of the Air Force answered others on the launch vehicle work and the general state of readiness for the flight.[24]

The turbulent February weather in Florida improved little in succeeding days, and the space pilot continued to train. On the 15th, for example, Glenn, learning upon awakening that the weather still held up the launch, slept until 9:30 a.m., had breakfast, spent two hours on the procedures trainer, and that afternoon studied the flight plan and technical documentation.

On February 19 the sky brightened; so did the spirits of the operations crew, who immediately began the 610-minute split countdown. During the afternoon the Department of Defense recovery force weather observers in the Atlantic reported to Williams that they had favorable weather conditions. At the Cape, however, the Weather Bureau personnel observed a frontal system moving across central Florida which, they surmised, could cause broken cloudiness over the Cape area on Tuesday morning (February 20). Williams, hoping for the best, decided to continue and ordered the launch crew to pick up the second half of the countdown at 11:30 p.m. on the evening of the 19th.[25]

Meanwhile Glenn restudied the detailed mission sequence, first reviewing the countdown progress and then looking over his flight plan and checking the equipment list. That afternoon he attended another "final" mission review meeting, called by Williams. Glenn believed an astronaut should study his spacecraft's systems until the last possible minute before a flight. Shortly before he went to bed that night he read a section in the flight controller's handbook on the automatic stabilization and control system.[26]

## An American in Orbit

Glenn was awakened once again at 2:20 a.m. on February 20. After showering, he sat down to a breakfast of steak, scrambled eggs, toast, orange juice, and coffee. At 3:05 the astronauts' flight surgeon, William Douglas, gave him a brief physical examination.

Douglas, Glenn, and his suit technician, Joe W. Schmitt, were only three of a multitude hard at work on the cloudy February morning. In the Mercury Control Center procedures log, the flight control team noted at 3:40 that they were "up and at it." The team immediately conducted a radar check, and although ionospheric conditions made the results poor the controllers believed the situation would improve soon. So they went on to check booster telemetry and the Control Center's voice intercom system, both of which were in good order. Shortly thereafter they found a faulty communication link that was supposed to be obtaining information about the capsule's oxygen system, but within minutes they had corrected the problem.[27]

At 4:27 a.m. Christopher Kraft, sitting before his flight director's console, received word that the global tracking network had been checked out and was ready. In Hangar S, Douglas placed the biosensors on Glenn, and Joe Schmitt began helping the astronaut don his 20-pound pressure suit. At 5:01 the Mercury Control Center learned that the astronaut was in the van and on his

way to the launch pad. The van moved slowly and arrived at 5:17, 20 minutes behind schedule. But the delay was of little consequence, for at 5:25 (T minus 120 minutes) trouble had cropped up in the booster's guidance system. Since this came during the built-in 90-minute hold part of the countdown for the astronaut insertion activity, the delay was not likely to halt the readying procedures for very long. The installation of a spare unit and an additional 45 minutes required for its checkout, however, made a total of 135 minutes lost.[28]

Because of overcast weather and the guidance problem in the Atlas, Glenn relaxed comfortably in the van until 5:58, when the sky began to clear. The capsule and booster validation checks were progressing normally as he emerged from the van, saluted the onlookers, and boarded the gantry elevator. At 6:03, the operations team noted in its procedures log, the astronaut "put a foot into the spacecraft." Once inside *Friendship 7,* Glenn noticed that the respiration sensor—a thermistor attached to the astronaut's microphone in the air stream of his breath—had shifted from where it had been fixed during the simulated flight. Stanley C. White pointed out to Williams that a correction could only be made by opening the suit, a very tricky operation atop the gantry. So the two officials decided to disregard the slipped thermistor, even though faulty data would result. White advised the range to ignore all respiratory transmissions.[29]

At last the technicians began to bolt the hatch onto the spacecraft, but at 7:10, with the countdown proceeding and most of the 70 bolts secured, a broken bolt was discovered. Although Grissom had flown in MR–4 with a broken hatch bolt, Williams, taking no chances this time, ordered removal and repair. Taking the hatch off and rebolting would require about 40 minutes, so the operations team took this opportunity to run still another check of the guidance system on Atlas 109–D. Glenn evidently maintained his composure during this hold, with his pulse ranging between 60 and 80 beats per minute. When a little more than half of the bolts had been secured, he peered through the periscope and remarked to Scott Carpenter and Alan Shepard in the Control Center, "Looks like the weather is breaking up." [30]

Minutes later the hatch installation was completed and the cabin purge was started. A check of the cabin oxygen leakage rate indicated 500 cubic centimeters per minute, well within design specifications. At 8:05, T minus 60 minutes, the countdown continued, but after 15 minutes a hold was called to add about 10 gallons of propellant to the booster's tanks. Glenn had been busily going over his capsule systems checklist. As the holds continued, he occupied his time and relieved the pressure at various points on his cramped body by pulling on the bungee-cord exercising device in front of his head in the capsule. The countdown resumed while the liquid oxygen was being pumped aboard the Atlas, but at T minus 22 minutes, 8:58, a fuel pump outlet valve stuck, causing still another hold.[31]

At that point in the countdown, Glenn, the blockhouse and Control Center crews, and workers scurrying around and climbing on the gantry were joined by some 100 million people watching television sets in about 40 million homes





*Above, Glenn leaves Hangar S with Dr. William K. Douglas (center) and Joe W. Schmitt. The launch (above right). At right, Army Larc stands ready for emergency recovery. Below right, Mercury Control's big radar follows the launch trajectory.*





**Flight of**
***Friendship 7***
**Feb. 20, 1962**



*Glenn photographs the flattened sun of an orbital sunset.*

*Mercury Control mans its bank of flight monitoring consoles.*





*On Grand Turk Island, Glenn continues debriefing for, left to right, Kenneth S. Kleinknecht and John J. Williams of STG.*

throughout the United States. Countless others huddled around radios in their homes or places of business and about 50,000 "bird watchers" stood on the beaches near Cape Canaveral, squinting toward the erect rocket gleaming in the distance. Some of the more hearty and sun-tanned spectators had been at the Cape since mid-January and had organized trailer towns, complete with "mayors." Mission announcer Powers, popularly known as "the voice of Mercury Control," who had been at his post in the Control Center since 5 o'clock that morning, went on the air to advise the waiting public of the status of the countdown and the cause for the present hold.

With the stuck valve cleared, the count picked up at 9:25, but another suspenseful moment came at 6½ minutes before launch time, when the Bermuda tracking station experienced an electrical power failure. Although the breakdown was brief, it took several more minutes to steady the Bermuda computer.

At 9:47, after two hours and 17 minutes of holds and three hours and 44 minutes after Glenn entered his "office," *Friendship 7* was launched on its orbital journey. The Atlas, supported by its tail of fire, lifted off its pad, and Powers made the announcement that this country had waited three long years to hear: "Glenn reports all spacecraft systems go! Mercury Control is go!" As Atlas 109–D lunged spaceward, Glenn's pulse rate climbed to 110, as expected. The Atlas and its control systems telemetered signals that they were functioning perfectly.[32]

Half a minute after liftoff the General Electric-Burroughs guidance system locked onto a radio transponder in the booster to guide the vehicle until it was through the orbital insertion "window." The vibration at liftoff hardly bothered Glenn, but a hundred seconds later at max-q he reported, "It's a little bumpy about here." After the rocket plunged through the max-q region, the flight smoothed out; then two minutes and 14 seconds after launch, the outboard booster engines cut off and dropped away. Glenn saw a wisp of smoke and fleetingly thought the escape tower had jettisoned early, but that event occurred exactly on time, 20 seconds later.[33]

When the tower separated, the vehicle combination pitched over still further, giving Glenn his first view of the horizon, which he described as "a beautiful sight, looking eastward across the Atlantic." Vibration increased as the fuel supply spewed out the sustainer engine nozzle, then abruptly stopped when the sustainer shut down. The sustainer had accelerated the capsule to a velocity only seven feet per second below nominal and had put the Atlas into an orbital trajectory only .05 of a degree low. Joyously the operations team noted in the log, "9:52- - -We are through the gates." Glenn received word that he could make at least seven orbits with the orbital conditions MA–6 had achieved. To Goddard's computers in Maryland the orbital insertion conditions appeared good enough for almost 100 orbits.[34]

Although the posigrade rockets kicked the capsule loose from the booster at the correct instant, the five-second rate-damping operation started two and a half seconds late. This brief lapse caused a substantial initial roll error just as the

capsule began its turnaround. The attitude control system managed the deviation very well, but it was some 38 seconds before *Friendship 7* dropped into its proper orbital attitude. Turnaround spent 5.4 pounds of fuel from a total supply of 60.4 pounds (36 for automatic and 24.4 for manual control). Despite his slow automatic positioning maneuver, Glenn made his control checks with such ease that it seemed, he said, as if he were sitting in the procedures trainer. As Voas had asked him to do, the astronaut peered through the window at the tumbling Atlas tankage. It had come into view exactly as Ben F. McCreary of MSC had predicted it would. He could see the spent vehicle turning end over end, and he called out estimates of distances between the separating vehicles: "One hundred yards, two hundred yards." At one point Glenn's estimate matched the telemetry signal exactly. He visually tracked the sustainer intermittently for about eight minutes.[35]

Glenn, noticing the onset of weightlessness, settled into orbital free flight with an inertial velocity of 17,544 miles per hour and reported that zero g was wholly pleasant. Although he could move well and see much through his trapezoidal window, he wanted to see even more. "I guess I'd like a glass capsule," he later quipped. Weightlessness also helped him as he used the hand-held camera. When his attention was drawn to a panel switch or readout, he simply left the "weightless" camera suspended and reached for the switch. Dutifully carrying out all of the head and body movements requested by Voas, he experienced none of the sensations reported by Gherman Titov. While any Glenn-Titov comparison might be ruled invalid since Titov reportedly became nauseated on his sixth orbit and Glenn flew only three orbits, MA–6 at least was to demonstrate to the American medical community that there were no discernible adverse physiological effects from over four hours of weightlessness.[36]

The first orbit of *Friendship 7* began ticking off like clockwork with the Canary Islands reporting all capsule systems in perfect working order. Looking at the African coastline, and later the interior over Kano, Nigeria, Glenn told the tracking station team that he could see a dust storm. Kano flight communicators replied that the winds had been quite heavy for the past week.[37]

Glenn, completing his spacecraft systems checks over the Canaries, had commented that he was getting a little behind in his schedule but that all systems still were "go." Then, over Kano, he had commenced his own first major yaw adjustment, involving a complete turnaround of the capsule until he was facing his flight path. Glenn noted that the attitude indicators disagreed with what he could see were true spacecraft attitudes. Despite the incorrect panel readouts, he was pleased to be facing the direction his spacecraft was going.[38]

Over the Indian Ocean on his first orbit, Glenn became the first American to witness the sunset from above 100 miles. Awed but not poetically inclined, the astronaut described the moment of twilight simply as "beautiful." Space sky was very black, he said, with a thin band of blue along the horizon. He could see the cloud strata below, but the clouds in turn prevented his seeing a mortar flare fired by the Indian Ocean tracking ship. Glenn described the remarkable

sunset: the sun went down fast but not quite as quickly as he had expected; for five or six minutes there was a slow but continuous reduction in light intensity; and brilliant orange and blue layers spread out 45 to 60 degrees on either side of the sun, tapering gradually toward the horizon.

On the nightside of Earth, nearing the Australian coastline, Glenn made his planned star, weather, and landmark observations. He failed to see the dim light phenomenon of the heavens called the zodiacal light; he thought his eyes had not had sufficient time to adapt to the darkness. Within voice radio range of the Muchea, Australia, tracking station, Glenn and Gordon Cooper began a long space-to-Earth conversation. The astronaut reported that he felt fine, that he had no problems, and that he could see a very bright light and what appeared to be the outline of a city. Cooper answered that he probably saw the lights of Perth and Rockingham. Glenn also said that he could see stars as he looked down toward the "real" horizon—as distinguished from the haze layer he estimated to be about seven or eight degrees above the horizon on the nightside—and clouds reflecting the moonlight. "That sure was a short day," he excitedly told Cooper. "That was about the shortest day I've ever run into." [39]

Moving onward above the Pacific over Canton Island, Glenn experienced an even shorter 45-minute night and prepared his periscope for viewing his first sunrise in orbit. As the day dawned over the island, he saw literally thousands of "little specks, brilliant specks, floating around outside the capsule." Glenn's first impression was that the spacecraft was tumbling or that he was looking into a star field, but a quick hard look out of the capsule window corrected this momentary illusion. He definitely thought the luminescent "fireflies," as he dubbed the specks, were streaming past his spacecraft from ahead. They seemed to flow leisurely but not to be originating from any part of the capsule. As *Friendship 7* sped over the Pacific expanse into brighter sunlight, the "fireflies" disappeared.[40]

The global circuit was proceeding without any major problems, and Glenn still was enjoying his extended encounter with zero g. He ran into some bothersome interference on his broadband HF radio when he tried to talk with the Hawaiian site at Kauai. An aircraft from the Pacific Missile Range tried unsuccessfully to locate the noise source. Other than the mystery of the "fireflies" and the intermittent HF interference, the mission was going fine, with the capsule attitude control system performing perfectly.

Then the tracking station at Guaymas, Mexico, informed the control center in Florida that a yaw reaction jet was giving Glenn an attitude control problem that, as he later recalled, "was to stick with me for the rest of the flight." This was disheartening news for those in the operations team, who remembered that a sticking fuel valve discovered during the second orbital pass of the chimpanzee Enos had caused the early termination of MA–5. If Glenn could overcome this control problem he would furnish confirmation for Williams' and others' contention that man was an essential element in the loop. If the psychologists'

failure task analyses were correct, the flexibility of man should now demonstrate the way to augment the reliability of the machine.

Glenn first noticed the control trouble when the automatic stabilization and control system allowed the spacecraft to drift about a degree and a half per second to the right, much like an automobile with its front wheels well out of alignment. This drift initiated a signal in the system that called for a one-pound yaw-left thrust, but there was no rate response. Glenn immediately switched to his manual-proportional control mode and eased *Friendship 7* back to orbital attitude. Then, switching from mode to mode, he sought to determine how to maintain the correct attitude position with the least cost in fuel. He reported that fly-by-wire seemed most effective and economical. Mercury Control Center recommended that he stay with this control system. After about 20 minutes the malfunctioning thruster mysteriously began working again, and with the exception of a few weak responses it seemed to be working well by the time Glenn was over Texas. After only about a minute of automated flight, however, the opposing yaw-right thruster ceased to function. When similar trials and waiting did not restore the yaw-right jet, Glenn realized that he would have to live with the problem and become a full-time pilot responsible for his own well-being.[41]

To the operations team at the Cape and to the crews at the tracking sites, Glenn appeared to be coping with his attitude control problem well, even though he had to omit many of his observational assignments. But a still more serious problem bothered the Cape monitors as *Friendship 7* moved over them. An engineer at the telemetry control console, William Saunders, noted that "segment 51," an instrument providing data on the spacecraft landing system, was presenting a strange reading. According to the signal, the spacecraft heatshield and the compressed landing bag were no longer locked in position. If this was really the case, the all-important heatshield was being held on the capsule only by the straps of the retropackage. Almost immediately the Mercury Control Center ordered all tracking sites to monitor the instrumentation segment closely and, in their conversations with the pilot, to mention that the landing-bag deploy switch should be in the "off" position. Although Glenn was not immediately aware of his potential danger, he became suspicious when site after site consecutively asked him to make sure that the deploy switch was off. Meanwhile the operations team had to decide how to get the capsule and the astronaut back through the atmosphere with a loose heatshield. After huddling for several minutes, they decided that after retrofire the spent retropackage should be retained to keep the shield secure during reentry. William M. Bland, Jr., in the control center, hurriedly telephoned Maxime A. Faget, the chief designer of the Mercury spacecraft, in Houston, to ask if there were any special considerations they needed to know or to watch. Faget replied that everything should be all right, providing all the retrorockets fired. If they did not, the retropack would have to be jettisoned, because any unburned solid propellant would ignite during reentry.

The operations team concluded that retaining the retropack was the only possible way of holding the shield in place and protecting Glenn during the early portion of his return to the dense atmosphere. The men in Mercury Control realized that the metallic retropack would burn away, but they felt that by the time it did, aerodynamic pressures would be strong enough to keep the shield in place. The decision once made, the members of the operations team fought off a gnawing uneasiness throughout the rest of the flight.[42] This uneasiness was transmitted to the TV and radio audience before actual retrofire.

Meanwhile *Friendship 7* was vaulting the Atlantic on its second orbital pass, and Glenn was busy keeping his capsule's attitude correct and trying to accomplish as many of the flight plan tasks as possible. He had advised Virgil Grissom at Bermuda that the oculogyric test, involving visually following a light spot, had just been completed. Near the Canary Islands the sun, streaming through his window, made Glenn a little warm, but he refused to adjust the water coolant control on his suit circuit. This time around he observed that evidently the "fireflies" outside the spacecraft had no connection with the gas from the reaction control jets. Glenn skillfully positioned his ship to take some photographs of the cloud masses and Earth spinning past beneath him. As he mused over a small bolt floating around inside the capsule, the Kano and Zanzibar sites monitoring the capsule suddenly noted a 12 percent drop in the secondary oxygen supply.[43]

Meanwhile the Indian Ocean tracking ship was preparing for the second-pass observation experiment. Battened down for heavy weather, the Mercury support crew decided that releasing balloons for Glenn to try to see was out of the question and instead they fired star-shell parachute flares. Glenn, however, was able to observe only lightning flashes in the storm clouds below.

Over the Indian Ocean, Glenn finally decided to adjust the water coolant flow in the suit circuit to improve on a condition he described as "comfortably warm." By the time he was over Woomera, Australia, the light signal warning of excess cabin water told him that the humidity level was rising. From then on throughout the rest of the flight he had to balance his suit cooling carefully against the cabin humidity, but the temperature inside his suit was never more than moderately uncomfortable. Another warning light appeared over Australia, indicating that the hydrogen peroxide fuel supply for the automatic system was down to 62 percent. Mercury Control Center recommended letting the capsule drift in orbit to conserve fuel. Glenn also complained that the roll horizon scanner did not seem to be working too well on the nightside of Earth and that it was difficult for him to obtain a visual reference to check the situation. To get a better view of Earth's horizon he pitched the spacecraft slightly downward, which helped some.

For the remainder of the second orbit and while going on into the third pass, *Friendship 7* encountered no new troubles. Glenn continued to control his attitude without allowing too much drift, and consequently consumed considerably more fuel than the automatic system would have used had the control system been working normally. He had used six pounds from the automatic tank and 11.8

pounds from the manual on the second orbit, or almost 30 percent of his total supply. While he had to pay close attention to the control system to hold the fuel expenditure as low as possible, he still had opportunities for making observations, photographing the constellation Orion, and executing a third 180-degree yaw maneuver.

On the last orbital circuit of *Friendship 7*, the Indian Ocean tracking ship gave up on the release of objects for pilot observation; cloud coverage was still too thick. There was still time enough for a little joking between Cooper, at Muchea, and Glenn. The pilot quite formally requested the "down under" communicator to tell General David Shoup, Commandant of the Marine Corps, that three orbits should suffice for his minimal monthly requirement of four hours' flying time. Glenn asked that he be certified as eligible for his regular flight pay increment.

Now that *Friendship 7* was halfway through its last orbit, Williams and Kraft decided to try once more to find out all they could about the heatshield before Glenn and his ship plunged through the searing reentry zone. At Kraft's order, the Hawaiian tracking site told Glenn to place the landing bag deploy switch in the automatic position. Then, if a light came on, he should enter with the retropack in place. Coupling this with past queries about this switch, Glenn thoroughly deduced his situation. He ran the test, reported that no light appeared, and added that he could hear no loose bumping noises when the spacecraft's attitude changed. The ground crew leaders differed regarding the best possible procedure to follow: Capsule systems monitors in the Control Center thought that the retropack should be jettisoned, while the data reduction crew urged that it be retained. This left the final decision up to Kraft and Williams. They weighed the information they had received and decided it would be safer to keep the retropack. Walter Schirra, the California communicator, passed the order to Glenn to retain the retropack until he was over the Texas tracking station.[44]

Meanwhile Glenn was preparing for reentry. Keeping the retrorocket package on meant that he had to retract the periscope manually and activate the .05-g sequence by pushing the override switch. Then, while nearing the California coastline, a little more than four hours and 33 minutes after launch, the spacecraft assumed its critical retrofire attitude alignment and the first retrorocket fired. "Boy, feels like I'm going halfway back to Hawaii," Glenn reported. Seconds later, in orderly succession, the two remaining rockets executed the braking process. The attitude controls maintained spacecraft position exactly throughout the retrofire sequence; about six minutes after the first retrorocket fired, Glenn carefully pitched the conical end of the spacecraft up to the correct, 14-degree negative-pitch attitude for its downward plunge through the atmosphere.

Now came one of the most dramatic and critical moments in all of Project Mercury. In the Mercury Control Center, at the tracking stations, and on the recovery ships ringing the globe, engineers, technicians, physicians, recovery personnel, and fellow astronauts stood nervously, stared at their consoles, and listened to the communications circuits. Was the segment 51 reading on the landing bag and

heatshield correct? If so, would the straps on the retropack keep the heatshield in place long enough during reentry? And even if they did, was the thermal protection designed and developed into the Mercury spacecraft truly adequate? Would this, America's first manned orbital flight, end in the incineration of the astronaut? The whole Mercury team felt itself on trial and awaited its verdict.

Glenn and *Friendship 7* slowed down during their long reentry glide over the continental United States toward the hoped-for splashdown in the Atlantic. The Corpus Christi station told Glenn to retain the retropack until the g meter before him read 1.5. Busily involved with his control problems, Glenn reported over the Cape that he had been handling the capsule manually and would use the fly-by-wire control mode as a backup. Mercury Control then gave him the .05-g mark, and the pilot punched the override button, saying later that he seemed to be in the fringes of the g field before he pushed. Almost immediately Glenn heard noises that sounded like "small things brushing against the capsule." "That's a real fireball outside," he radioed the Cape, with a trace of anxiety perhaps evident in his tone. Then a strap from the retropackage swung around and fluttered over the window, and he saw smoke as the whole apparatus was consumed. Although his control system seemed to be holding well, his manual fuel supply was down to 15 percent, with the deceleration peak still to come. So he switched to fly-by-wire and the automatic tank supply.[45]

*Friendship 7* came now to the most fearful and fateful point of its voyage. The terrific frictional heat of reentry enveloped the capsule, and Glenn experienced his worst emotional stress of the flight. "I thought the retropack had jettisoned and saw chunks coming off and flying by the window," he said later. He feared that the chunks were pieces of his ablation protection, that the heatshield might be disintegrating, but he knew there was nothing to gain from stopping work.[46]

Shortly after passing the peak g region, the spacecraft began oscillating so severely that Glenn could not control the ship manually. *Friendship 7* swung far past the "tolerable" 10 degrees on both sides of the zero-degree point. "I felt like a falling leaf," Glenn would recall. So he cut in the auxiliary damping system, which helped to stabilize the large yaw and roll rates to a more comfortable level. Fuel in the automatic tanks, however, was getting low. Obviously the heatshield had stayed in place; Glenn was still alive. But now he wondered whether his capsule would remain stable down to an altitude at which the drogue parachute could be deployed safely.

The pilot's fears proved real when both fuel supplies ran dry. Automatic fuel gave out at 111 seconds, and manual fuel depleted at 51 seconds, before the drogue deployment. The oscillations rapidly resumed, and at about 35,000 feet Glenn decided he had better try to deploy the drogue manually lest the spacecraft flip over into an antenna-downward instead of a heatshield-downward position. But just as he lifted his hand toward the switch, the drogue automatically shot out at 28,000 feet instead of the nominal 21,000. Suddenly the spacecraft straightened out and, as Glenn reported, "everything was in good shape."[47]

All systems in *Friendship 7* worked with precision for the remainder of the flight. At about 17,000 feet the periscope opened again for the pilot's use. Glenn, instead, glanced out the window, but it was coated with so much smoke and film that he could see very little. The spacecraft stabilized in its descent; the antenna section jettisoned; and Glenn, with immense relief, watched the main chute stream out, reef, and blossom. The Florida control center reminded Glenn to deploy the landing bag. He flipped the switch, saw the green light confirmation, and felt a comforting "clunk" as the shield and impact bag dropped into position four feet below the capsule. Glenn watched the ocean coming up to meet him and braced as the gap closed. Jolted by an impact that was more reassuring than stunning, he bobbed in the water, checked his watertight integrity, and relayed his elation that a successful MA–6 mission seemed assured.[48]

*Friendship 7* had splashed into the Atlantic about 40 miles short of the predicted area, as retrofire calculations had not taken into account the spacecraft's weight loss in consumables. The *Noa,* a destroyer code-named Steelhead, had spotted the spacecraft during its descent. From a distance of about six miles the destroyer radioed Glenn that it could reach him shortly. Seventeen minutes later, the *Noa* cruised alongside; a sailor smartly cleared the spacecraft antenna; and Boatswain's Mate David Bell deftly attached a davit line for pickup. During the hoist upward the spacecraft bumped solidly against the side of the destroyer. Once *Friendship 7* was lowered to the mattress pallet, Glenn began removing paneling, intending to leave the capsule through the upper hatch. But it was too hot, and the operation was too slow for the already long day. So he told the ship's crew to stand clear, carefully removed the hatch detonator, and hit the plunger with the back of his hand. The plunger recoiled, cutting Glenn's knuckles slightly through his glove and giving him the only injury he received during the whole mission. A loud report indicated that the hatch was off. Eager hands pulled out the smiling astronaut, whose first words were "It was hot in there."

Lieutenant Commander Robert Mulin of the Navy and Captain Gene McIver of the Army, physicians assigned to the Mercury recovery team, described Glenn as being hot, sweating profusely, and fatigued. He was lucid but not loquacious, thirsty but not hungry. After drinking a glass of water and showering, he became more talkative. Asked if he felt any "stomach uneasiness" either during the flight or while he lolled the 17 minutes in the floating spacecraft waiting for pickup, Glenn admitted only to some "stomach awareness," beginning after he was down on the water. But there was no nausea, and the examining physicians assured themselves that Glenn's condition was caused by heat, humidity, and some dehydration. He had lost five pounds, five ounces from his preflight weight of 171 pounds, seven ounces. He had consumed the equivalent of only 94 cubic centimeters of water, in the form of applesauce puree, during the flight, while his urine output was 800 cubic centimeters. He also had perspired profusely while awaiting pickup.

Glenn's temperature an hour after landing was 99.2 degrees, or only a degree

higher than his preflight reading, and by midnight he recorded a normal temperature. His blood pressure registered only a fraction higher than the preflight readings. The condition of his heart and lungs was normal before and after the mission, and there was nothing unusual about his skin except the superficial abrasions on the knuckles, caused by opening the hatch. By the time President Kennedy called his personal congratulations by radio telephone to Glenn aboard the *Noa,* the "wonderful trip—almost unbelievable" was over, Glenn was safe and sound, and 100 million American television viewers had happily ceased their vigil.

After recording on tape a "self-debriefing" aboard the *Noa,* Glenn was transferred to the carrier *Randolph,* where his chest was x-rayed, an electrocardiogram was made, and the initial phase of the technical debriefing was started. From there the astronaut was transported to Grand Turk Island, where a much more thorough physical began about 9:30 p.m., under the direction of Carmault B. Jackson, assistant to Flight Surgeon Douglas. February 20, 1962, proved to be "a long day at the office" for Glenn. After exhaustive tests and observations the attending physicians could find no adverse effects from Glenn's threefold circumnavigation in space. Technical debriefings continued for two days on the island and then moved to the Cape for another day's session.

The postflight analysis of Glenn's use of the three-axis handcontroller during reentry showed that about half of the thrust pulses he initiated opposed the direction of spacecraft motion, as they were supposed to. But the other half of the handcontroller movements either reinforced oscillating motions or had no net damping effect. The issue of "pilot-induced error" was picked up by some newsmen and reported as a controversy rather than a problem.

Now that the primary objectives of Project Mercury had been achieved at last in grand style, the drive for perfection in performance, so indispensable to manned space flight, still did not slow down.[49]

## The Hero

The American reaction to this country's first manned orbital flight was a mixture of relief, pride, and exaltation. From the Rose Garden at the White House, President Kennedy echoed the sentiments of the Nation: [50]

> I know that I express the great happiness and thanksgiving of all of us that Colonel Glenn has completed his trip, and I know that this is particularly felt by Mrs. Glenn and his two children.
>
> I also want to say a word for all of those who participated with Colonel Glenn at Canaveral. They faced many disappointments and delays—the burdens upon them were great—but they kept their heads and they made a judgment, and I think their judgment has been vindicated.
>
> We have a long way to go in this space race. But this is the new ocean, and I believe the United States must sail on it and be in a position second to none.

Not only Americans but friendly foreigners hastened to add their praises for Glenn and Project Mercury. India's news media gave the flight top billing over an important national election. Most of the South American press viewed the space gap as already closed or being closed, while a sense of relief that a more favorable balance of power existed was evident in the African newspapers. Western Europeans were pleased with the openness of the undertaking, with the fact, frequently mentioned, that the United States had not used this momentous event to intimidate either opponent or neutral, and that the astronaut had kept his inflight remarks strictly apolitical. Numerous expressions of hope were voiced, as Khrushchev suggested and Kennedy repeated that Russians and Americans could enter into some sort of cooperative space program.[51]

The men of NASA, the Defense Department, and the aerospace industry viewed the feat more prosaically. They realized something of its impact on mankind, but most of their pride stemmed from the smooth-working demonstration of their space hardware and the recovery forces in action. And their interest quickly returned to the tasks of full exploitation of men and machines for Mercury.

Those who in the past had been the targets of technical kibitzing, domestic skepticism, and political pressure now were lauded by the American press for having "stuck by their guns." Periodicals praised Hugh L. Dryden, Robert R. Gilruth, Williams, Faget, Kraft, George M. Low, and Hartley A. Soulé, the "leaders of this technical team who did their work on civil service pay and sold no serial rights to national magazines. . . ." [52]

The MA–6 honors and celebrations consumed several days. Glenn, his family, Vice-President Johnson, and the Mercury entourage passed in review on February 26 before an estimated 250,000 people lining rainy streets in Washington, after which the astronaut gave a 20-minute informal report to a joint session of Congress. New York City proclaimed March 1 " John Glenn Day," and Mayor Robert Wagner presented medals to Glenn and Gilruth. The next day there was an informal reception in honor of the orbiting American at United Nations Headquarters. Glenn then journeyed to his home town, New Concord (population 2300), Ohio, where about 75,000 greeted him on March 3.

While everyone else feted Glenn, Mercury and contractor engineers at the Cape subjected his spaceship to a minute examination. Except for the usual discoloration, the interior and exterior of the capsule were in excellent condition. In several places where there were separations between the shingles, deposits of aluminum alloy had accumulated from the disintegration of the retrorocket package during reentry. A brownish film of undetermined origin covered the exterior surface of the window. Heatshield slices and cores showed about the same minor char depth found after the MA–4 and MA–5 missions; the center plug was sticking out about half an inch. There was also a wedge-shaped darker area on the shield, striated by several radial marks about four inches long, which the inspectors theorized was caused by the slipping retropack. The investigation

team also found that the rotary switch that was to be actuated by the heatshield deployment had a loose stem, causing the electrical contact to break when the stem was moved up and down. This, they believed, accounted for the false deploy signal that worried everyone so much during the flight. Although there were several tears in the landing bag, caused either by impact or retrieval handling, for the first time no cables or straps in the landing system were broken. And while the lower pressure bulkhead again was slightly damaged, the equipment there escaped harm.[53]

After this thorough postflight analysis, Glenn's spacecraft, McDonnell capsule No. 13, went on a global tour, popularly known as the "fourth orbit of *Friendship 7*." Literally millions of people stood patiently in line to look inside the spacecraft as it was exhibited in 17 countries and Hawaii. By August 1962 *Friendship 7* had reached the "Century 21 Exposition" at Seattle. There, thousands more viewed the craft that had carried man on an orbital journey through space. Finally, on the first anniversary of its voyage, *Friendship 7* came officially to rest near the Wright Brothers' original airplane and Lindbergh's *Spirit of St. Louis* in the Smithsonian Institution.[54]

## Program Growth

The dramatic series of events surrounding the MA–6 mission tended to obscure what was happening elsewhere in the national space program. While Project Mercury finally was fulfilling its prime objective, NASA picked the launch vehicle for its Apollo program. Headquarters announced on January 9, 1962, that a "Super Saturn" (also known as "Advanced Saturn" and "Saturn C–5") would be the Moon program rocket. The Saturn was then described as being as tall as a 27-story building generating 7.5 million pounds of thrust in its first stage, which would make it about 20 times more powerful than the Atlas. On January 25, the Marshall Space Flight Center received orders from NASA Headquarters to develop this booster that could support manned circumlunar flights and manned lunar landings. The Saturn was to place 120 tons in low-Earth orbit or send 45 tons of spacecraft toward the Moon. At the same time, the public got its first view of drawings of the Apollo and Gemini spacecraft.[55]

When the House Committee on Science and Astronautics opened its annual budget hearings on February 27, 1962, among the first witnesses to testify were John Glenn, Alan Shepard, and Virgil Grissom. Representative George P. Miller of California, chairman of the committee, introduced the three as "men who have been closest to the angels and still remain on Earth." All committee members expressed their satisfaction with the management of Project Mercury, and they reminded NASA that the agency was the committee's protege. Every tax dollar required to make Project Mercury and the rest of the civilian space program a success so far had resulted from the committee's study, approval, and authorization.[56]





*Above, President Kennedy rides with Glenn and Gen. Leighton I. Davis at Cocoa Beach. At right, Glenn talks to a joint session of the Congress in Washington. Below right, Glenn, his wife, and Vice-President Lyndon B. Johnson are welcomed by 4 million in New York. Finally, in Washington (below),* Friendship 7 *is presented to the Smithsonian Institution. Shown here are Senator Clinton P. Anderson, Glenn, and NASA Deputy Administrator Hugh L. Dryden.*







*Astronauts Grissom, Shepard, and Glenn testify before House Committee on Science and Astronautics on February 28, 1962. Standing behind them are (left to right) Representatives Ken Hechler, Alphonzo Bell, and Perkins Bass, and Paul Dembling, Director, NASA Office of Legislative Affairs.*

After the astronauts had made brief statements and answered some questions posed by the committee members, Administrator James E. Webb outlined the NASA budget request for fiscal year 1963. The total NASA request was for $3,787,276,000, of which $2.26 billion was earmarked for developing Gemini and Apollo and for further exploration with Mercury in manned space flight. Robert Gilruth testified about the Mercury portion of NASA's undertaking. By August 1962, when Congress passed the authorization bill, the NASA appropriation had been pruned to $3,644,115,000. This reduction included $90 million from research, development, and operational requests, and about $52.8 million asked for construction of new facilities. But the total NASA money bill, coupled with almost $1 billion that the Department of Defense received for its space projects, meant that the Nation was going to spend almost $5 billion annually on its space efforts.[57] The second phase of the Space Age seemed about to commence.



*Constant communication of status information from one part of STG to another, from STG to NASA Hq. and other elements of the Government, and between STG and its contractors occupied much of the time of operating and staff personnel. At right is a typical preflight briefing, this one taking place at the Air Force Ballistic Missile Division for personnel of BMD, SSD, and Aerospace Corp.; involved in this particular discussion are, left to right, Christopher C. Kraft of STG, Byron G. McNabb of General Dynamics/Astronautics, and Bernhard A. Hohmann of Aerospace Corp. And in the tense atmosphere of Mercury Control during a flight, communication was at a premium. Below, in the front row of the VIP viewing room at Mercury Control, George Low of NASA Hq. leans forward to make notes for the report that he forwarded to the NASA Administrator immediately after every Mercury mission; next to him D. Brainerd Holmes, NASA Deputy Associate Administrator for Manned Space Flight, and Robert R. Gilruth, Director of STG, listen to the flight narration and watch the display board.*



Meanwhile the Manned Spacecraft Center had been undergoing rapid changes, even though it was still located at the Langley Research Center pending the move to Houston. On January 15, 1962, the Mercury Project Office was established, reporting directly to Gilruth, together with the Gemini and Apollo management offices. Kenneth S. Kleinknecht, a former leader in NASA's X–15 project and technical assistant on Gilruth's staff since January 11, 1960, was picked to manage the completion of Mercury's program. Under its charter, the Mercury Project Office was "responsible for the technical direction of the McDonnell Aircraft Corporation and other industrial contractors assigned work on the Mercury Project." [58]

Project Office staffing and division of duties had been completed by the end of January. Kleinknecht chose William Bland, who had been associated with numerous engineering phases of the manned satellite enterprise since its inception, as his deputy. The internal labor divisions of the Office were: Project Engineering Office, Project Engineering Field Office (Cape), Engineering Operations Office, and Engineering and Data Measurements Office. At the outset, 42 people worked in the Project Office primarily on scheduling, procurement, and technical monitoring tasks. The similar management organizations set up for the Gemini and Apollo programs had James A. Chamberlin (manager of Mercury until the inception of Project Gemini) and Charles W. Frick as their managers, respectively.[59]

Moving MSC from tidewater Virginia to the Gulf Coast of Texas could have had adverse effects on its staffing. Quite a number of the employees had long years of service with NACA and its successor NASA, and had established deep personal roots at Langley and around Hampton, Virginia. Now they would be uprooted and transplanted some 1500 miles away in Texas. Many would face inconvenience and monetary and personal losses resulting from the transfer. Stuart H. Clarke, chief of the Personnel Office of MSC, polled the staff to determine how many favored the move. Of 1152 employees, only 84 indicated that they would not go.[60] Gilruth and Williams decided that while people, records, and equipment were being transferred, the operational and Mercury Project Office activities should remain at Langley to prevent the disruption of Project Mercury's flight planning. This meant that management in Mercury would be directed from Langley at least through Mercury-Atlas 7.[61]

## The Slayton Case

Donald K. Slayton and Walter M. Schirra, pilot and backup, respectively, for Mercury-Atlas 7, had been in training side by side with Glenn and Carpenter since the team announcements were made after the MA–5 flight. On March 15, 1962, NASA announced that Slayton, because of an "erratic heart rate," had been replaced by Carpenter as the pilot for MA–7. The suddenness of this announcement surprised almost everyone, especially journalists who had begun turning out "human interest" copy about Slayton. The obvious question was: How could an astronaut, supposedly a perfect physical specimen, develop, of all things, a heart

condition? The truth was that Slayton had been under close medical surveillance for over two years, and he and his fellow astronauts each knew how precarious a thing is perfect health.

The astronauts' physician, William Douglas, recognized that Slayton had a condition medically termed as idiopathic atrial fibrillation—occasional irregularity of a muscle at the top of the heart, caused by unknown factors—when the astronauts first rode the centrifuge in August 1959 at Johnsville. Douglas noted Slayton was performing his tasks in magnificent fashion, but he still thought it best to consult with the chief of cardiology service at the Philadelphia Navy Hospital. The consultant assured Slayton and Douglas that the condition was of no consequence and should not influence Slayton's eventual choice as a flight astronaut. The astronaut's physician did not accept this appraisal as a final diagnostic decision. He and Slayton visited the Air Force's School of Aviation Medicine in San Antonio, Texas, where a member of the internal medicine staff voiced the same opinion. Sometime later Douglas learned that this individual wrote to Administrator James E. Webb, making a recommendation that Slayton should not be assigned a flight.

After sojourns at various medical centers, Douglas informed Mercury Director Gilruth of Slayton's condition during the fall of 1959. Gilruth, in turn, briefed NASA Headquarters in Washington. Douglas also relayed the information to the Air Force Surgeon General's office and was advised to take no action. For some time thereafter the "Slayton file" lay dormant. The astronaut was selected as a pilot in November 1961 and began training for his flight.

Shortly after the beginning of the new year, NASA Administrator Webb, remembering the dissenting vote he had received from an Air Force physician, and, mindful of the fact that Slayton was an Air Force officer on loan, directed a complete reevaluation of the case. In response Douglas called together Stanley White, William S. Augerson, and James P. Henry, physicians assigned to the Mercury program, to study the matter in detail. Their considered recommendation was that Slayton should continue as the pilot for MA–7. From MSC, Douglas journeyed to Washington to brief Brigadier General Charles H. Roadman and Colonel George M. Knauf, Chief and Deputy Chief of the Office of Space Medicine in NASA Headquarters. These doctors also recommended that Slayton remain on space flight status. The reopening of the case was brought to the attention of the Air Force Surgeon General, who convened a board of eight flight surgeons to review the matter. The MSC physician appeared before that body, presenting it with every facet of the medical file. Slayton also appeared. The board judged Slayton to be "fully qualified as an Air Force pilot and as an astronaut."

Administrator Webb referred the case to a group of three nationally eminent cardiologists—Proctor Harvey, professor of cardiology, Georgetown University; Thomas Mattingly, heart specialist, Washington Hospital Center; and Eugene Braunwall, National Institutes of Health. Their consensus was that they were

unable to state conclusively whether Slayton's physiological performance would be jeopardized by his heart condition. Because of this unknown, they felt that if NASA had an available astronaut who did not "fibrillate," then he should be used rather than Slayton. Braunwall added that if there was sufficient time he would like to subject Slayton to some physiological tests.[62]

Asked several years later if he had known about his heart condition when he was chosen for Project Mercury, Slayton replied:[63]

> No, I didn't, but in the examinations prior to the August 1959 centrifuge program at AMAL the medics discovered that my heart skipped a beat now and then. I went ahead with the centrifuge runs and began to watch myself very closely, noticing that quite often after supper my pulse would be irregular. I would get out and run a mile and everything was normal again. I was terribly concerned over what in my diet might be causing it, but every hypothesis turned up wrong. Concern in STG and even NASA Headquarters got so great in 1960 that I was sent to all kinds of exhaustive examinations under the best heart specialists in the country—in Philadelphia, San Antonio, and New York City. I was examined by different groups of heart specialists who could find nothing wrong. Even Paul Dudley White, Ike's personal physician, gave me a clean bill of health but rendered an operational rather than a diagnostic decision, recommending that the unknown factor in my heart murmur not be added to all the other unknowns for manned space flight.

The Slayton decision was irrevocable, even though Gilruth and William Douglas disagreed with the high-level medical verdict. Slayton, they felt, had withstood greater stresses in the training program than he would have experienced had he been rocketed into orbit. On the other hand, Administrator Webb, because of the unknown elements, concurred with the cardiologists that it was neither safe nor politic to subject an individual who had a heart condition, however slight, to the stresses of orbital flight when there were other flight-trained astronauts available.

Shortly after the replacement, Douglas, having completed a three-year tour of detached duty with NASA, returned to his career service, the Air Force. Some newsmen were quick to conclude that this action suggested bitterness. They had not known that Douglas had been invited to the medical hearings but had known that Douglas had been outspoken in his opposition to Slayton's removal from flight status. Stanley White denied the charge in a news conference, maintaining that Douglas' return to the Air Force had been arranged for "better than six months."[64] Of the original team of astronauts, Slayton had been considered the professional test pilot par excellence, largely because of his overwhelming experience and flight time. He soon became the coordinator of astronaut activities. He never abandoned hope that he still might make a space flight. As late as December 1964, more than a year and a half after Project Mercury had completed its last flight and when Project Gemini was nearing its first manned flight, the unlucky astronaut remarked, "I've never been grounded and I'm not now. I still hope to get my chance to go beyond the atmosphere."

## MA–7 Preparations

One would have expected, in keeping with the "backup" concept, that Schirra, the MA–7 alternate pilot, now would step in as prime astronaut. But in view of the numerous delays and consequent lengthy training preparations for MA–6, Williams, as the operations team leader, recommended to Gilruth that Carpenter, Glenn's backup pilot, was most primed for the upcoming mission. Carpenter had logged 79½ hours of preflight checkout and training time in Glenn's *Friendship 7*, more than twice the 31½ hours he would spend in his own *Aurora 7* for the same purposes.[65]

Although Glenn's mission had been highly successful, the Mercury operations team was still in the learning process. Experience with a component in the Mercury capsule or a flight procedure during the MA–6 orbital flight served to guide MA–7 mission planning. Glenn had shown that man definitely could be more than just a passenger, so the MSC planners adjusted the MA–7 flight plan to allow more pilot control of the mission. Combined yaw-roll maneuvers were scheduled to permit observation of the sunrise, as well as maneuvers to determine the use of day and night horizons, landmarks, and stars as navigation references. One of the more interesting planned innovations for Carpenter's voyage involved a period of inverted flight (head toward Earth) to determine the effect of Earth-up and sky-down on pilot orientation. Flight planners recognized the need for perceptual reorientation in space flight as well as for the motor skills that had been demonstrated so well by Glenn. The next Mercury mission ought to be as much of a scientific experiment as possible, not only to corroborate MA–6 but also to explore new possibilities with the manned Mercury spacecraft.[66]

Since Glenn had been able to respond to many of the scientific astronomical observation requests, Homer Newell, who had been Director of NASA's Office of Space Sciences since November 1, 1961, decided that the direction of the scientific portion of the manned space flight program should now become the responsibility of a formal committee. Jocelyn Gill again was chosen to serve as chairman of a group called the Ad Hoc Committee on Scientific Tasks and Training for Man-in-Space. Two days after receiving the mandate, Dr. Gill called a meeting of members, consisting of representatives from the various scientific disciplines, on March 16, 1962, to outline objectives, review past activities in this respect, present a preliminary analysis of the scientific debriefing of Glenn, and outline tasks and goals for the next meeting. One of the aims of the new committee was to devise a curriculum that would provide the astronauts with the best informational sources available about the spatial phenomena they might see. In addition to this, they proceeded to suggest several experiments to the Manned Spacecraft Center.[67]

So without jeopardizing either pilot safety or mission success, the MA–7 flight would be designed to yield as much scientific, as opposed to engineering, information as possible. Kleinknecht, head of the MSC Mercury Project Office,

named Lewis R. Fisher chairman of the Mercury Scientific Experiments Panel, as a parallel to the NASA Headquarters unit, to manage and arrange for the experiments being suggested. Fisher and his associates were charged with reviewing all proposed experiments from an engineering feasibility standpoint in terms of their scientific value, relative priority, and suitability for orbital flight.[68]

The Fisher panel first met at Cape Canaveral on April 24, 1962, and decided to emphasize five suggested experiments: releasing a multi-colored balloon that would remain tethered to the capsule, observing the behavior of liquid in a weightless state inside a closed glass bottle, using a special light meter to determine the visibility of a ground flare, making weather photographs with hand-held cameras, and studying the airglow layer—for which Carpenter would receive special training. The tethered balloon was a 30-inch mylar inflatable sphere, which was folded, packaged, and housed with its gas expansion bottle in the antenna canister. The whole balloon package weighed two pounds. Divided into five sections of different colors—uncolored aluminum, yellow, orange, white, and a phosphorescent coating that appeared white by day and blue by night—the balloon was to be cast off near perigee after the first orbital pass to float freely at the end of a 100-foot nylon line. The purposes of the balloon experiment were to study the effects of space on the reflection properties of colored surfaces through visual observation and photographic studies and to obtain aerodynamic drag measurements by use of a strain gauge.[69]

Some experimentation on the effects of reduced gravity on liquids previously had been conducted at Holloman Air Force Base, at the Air Force School of Aviation Medicine in San Antonio, and at the Lewis Research Center. But the duration of these experiments, involving parabolic airplane flights and drop-tower tests, had been necessarily short. Results of an extended study would have both immediate and long-range implications in manned space flight operations. Already the problem of gas or fuel vapor ullage in space vehicles and in storage tanks was causing some difficulties, and later there would be related problems in orbital rendezvous fuel transfer. Before fuel tanks and pumps for extended use in space could be designed, the behavior of surface tension and capillary action of liquids in the weightless state had to be determined. For this experiment the Lewis Center provided a small glass sphere containing a capillary tube with tiny semicircular holes at the bottom of the open tube. The sphere, only 20 percent filled, contained 60 milliliters of a mixture of distilled water, green dye, aerosol solution, and silicone. The liquid had a surface tension of 32 dynes per centimeter on Earth.

The Massachusetts Institute of Technology requested photographs of the daylight horizon through blue and red filters to define more precisely the Earth-horizon limb as seen from above the atmosphere. These findings would be particularly valuable for navigation studies in the Apollo program. The Weather Bureau wanted information on the best wavelengths for meteorological satellite photography. John A. O'Keefe and Jocelyn Gill at the Goddard Space Flight

Center and NASA Headquarters, respectively, wanted a distance measurement of the airglow layer above the horizon, its angular width, and a description of its characteristics, and for this experiment Carpenter was provided with a photometer and trained to use it. Paul D. Lowman, also of Goddard, requested special photography of the North American and African land masses. Lowman's interest was based on his studies of planetary surfaces, particularly regarding meteoroid impact features.[70]

A number of technical changes based on MA–6 mission results were made for MA–7, mostly involving deletions of certain equipment from the spacecraft to reduce weight. Kleinknecht's office eliminated the sofar bombs and radar chaff recovery aids, which seemed unnecessary in view of the effectiveness that had been demonstrated by the sarah beacon and dye markers. Other deletions included the knee and chest straps on the couch, which had bothered Grissom; the red filter in the window; the moderately heavy Earth-path indicator; and the instrument panel camera, which had already gathered sufficient data.

Modifications made to improve spacecraft, network, and astronaut performance included a radio frequency change in the telemetry system to eradicate transmission interference like that experienced on Glenn's flight. The two landing-bag switches were rewired so that both had to be closed to activate the deploy signal. To correct temporarily the control problem experienced by Glenn, Karl F. Greil of the Mercury Project Office studied masses of data and concluded that the problem lay in the fuel line filters. So the dutch-weave filters in the fuel lines were replaced with platinum screens, and a stainless-steel fuel line was substituted. This was intended as an "interim fix," but it became permanent in the Mercury project for the later flights. Even the astronaut's attire underwent some modifications. Pockets were added on the upper sleeves and on the lower legs of the pressure suit for pencils, a handkerchief, and other small accessories. And the waterwing life vest, first carried by Glenn, was installed on the chest beneath the parabolic mirror. To add to Carpenter's comfort while he was waiting in his capsule on the launch pad, a new and more resilient liner was fitted in the couch.[71]

The three principal components of the MA–7 mission—spacecraft, launch rocket, and astronaut—were in preparation for several months. Spacecraft No. 18 was the first of these to reach the Cape, arriving on November 15, 1961. During its long checkout period by G. Merritt Preston's crew, this vehicle was reworked twice to incorporate lessons learned during MA–5 and MA–6. Some equipment and systems in the capsule had to be exchanged because what it had carried to Florida simply did not work properly. The original periscope, for example, failed to latch in the retracted position. Glenn's drogue parachute mortar supposedly had fired before the pilot triggered its button; the McDonnell engineers decided that a barostat in the recovery arming circuit should prevent another premature action. Since there still were questions concerning the temperature at different places on the capsule while it was in orbit, a device known as a

"low-level commutator" was added, and temperature pickups were strategically located at 28 points on the spacecraft to record temperature data on a tape recorder carried on board.[72]

When in March he learned that he would fly spacecraft No. 18, Scott Carpenter named his capsule *Aurora 7*. He chose this name deliberately, "Because I think of Project Mercury and the open manner in which we are conducting it for the benefit of all as a light in the sky. Aurora also means dawn—in this case the dawn of a new age. The 7, of course, stands for the original seven astronauts." Coincidentally, the astronaut as a boy had lived at the corner of Aurora and Seventh Avenues in Boulder, Colorado.

The Atlas, the astronaut, and the ground support personnel entered into their final preparatory phase in March 1962. On March 8, six days after the Air Force accepted it at the rollout inspection at the Convair factory in San Diego, Atlas 107–D arrived at the Cape and was erected on the pad. Since the previous Atlas had performed well in boosting Glenn into orbit and since the MA–7 launch requirements were to duplicate those of MA–6, few changes were necessary for 107–D. One alteration was a slight reduction in the staging time, from 131.3 to 130.1 seconds after liftoff, to improve the launch vehicle's ability to reach the precise center of the insertion "window."[73] Intensive training for the astronaut, his backup, and the tracking teams on the MA–7 mission began on March 16. Mission simulations, flight controller training, and an exercise of the Defense Department recovery forces proceeded much as they had for MA–6. The Atlantic tracking ship, however, was not on station for MA–7 because she was at a Baltimore shipyard, being converted into a command ship to support the longer-duration Mercury missions.[74]

At the time of Glenn's flight, the launch of MA–7 had been scheduled for the second week in April, but the installation of new components, such as the temperature survey instrumentation and the barostat in the drogue parachute circuit, as well as other work, delayed the launching until May. Also contributing to the postponement was an Atlantic Fleet tactical exercise that required participation by the recovery ships and aircraft for several weeks. The week beginning May 20 looked the most feasible for sending a second American into orbit.[75]

## Flight of *Aurora 7*

At 1:15 a.m., May 24, 1962, Scott Carpenter was awakened in his quarters in Hangar S at Cape Canaveral. He ate a breakfast of filet mignon, poached eggs, strained orange juice, toast, and coffee, prepared by his dietitian. During the next hour, starting about 2:15 a.m., he had a physical examination and stood patiently in his underwear as the sensors were attached at various spots on his lean body, and by 3:25 he had donned his silver suit and had it checked. Everything had gone so smoothly that Carpenter had time to relax in a contour chair while waiting to board the van.

At 3:45, Carpenter and his retinue, including Joe Schmitt and John Glenn, marched from the hangar and climbed aboard the vehicle for a slow ride to Pad 14, where *Aurora 7* sat atop the Atlas. Again there was a pause, during which a Weather Bureau representative presented a briefing to the astronaut-of-the-day, predicting a dispersal of the ground fog then hovering around the launch site. Finally, at 4:35, Carpenter received word from Mercury Control to ascend the gantry. Just before he boarded the elevator he stopped to swap greetings with and to thank the flight support crewmen. After the final checks in the gantry white room, the astronaut crawled into the capsule and got settled with only minor difficulties, and soon the capsule crew was bolting the hatch. This time all 70 bolts were aligned properly.[76]

Meanwhile the booster countdown was racing along. Christopher Kraft recalled that the countdown was "as near perfect as could be hoped for." The only thing complicating the prelaunch sequence was the persistent ground fog and broken cloudiness at dawn. Strapped in the contour couch, and finding the new couch liner comfortable, Carpenter was busy verifying his preflight checklist. Just 11 minutes before the scheduled launch time, the operations team decided that adequate camera coverage was not yet possible, and three consecutive 15-minute holds were called. Although Carpenter felt that he could continue in a hold status indefinitely, he was thirsty and drank some cold tea from his squeeze bottle supply. During the holds he talked with his wife Rene and their four children at the Cape, assuring them that all was well.[77]

The rising sun rapidly dispelled the ground fog. Then at 7:45 a.m., after the smoothest countdown of an American manned space mission to date, Mercury-Atlas 7, bearing *Aurora 7*, rose majestically off the pad while some 40 million people watched by television.[78]

Kraft, the flight director, described the powered phase of the flight as so "excellent" that the decision to "go-for-mission" was almost routine. Seventy-three seconds from launch, the booster's radio inertial guidance system locked on and directed the flight from staging until T plus 5:38 minutes. Actually this amounted to some 28 seconds after the Atlas sustainer engine had died, but no guidance inputs were possible after engine shutdown. Carpenter tried using the parabolic mirror on his chest to watch the booster's programming, but he could see only a reflection of the pitch attitude. At about 35,000 feet he noticed out his window a contrail, and then an airplane producing another contrail. The sky began to darken; it was not yet black, but it was no longer a light blue.

The booster performed much more quietly than Carpenter had expected from all its awesome power. Vibration had been slight at liftoff. Booster engine cutoff was smooth and gentle, but a few seconds later the noise accompanying maximum aerodynamic stress began to build up. A wisp of smoke that appeared out the window gave Carpenter the impression that the escape tower had jettisoned, but a glance showed that it was still there. Shortly thereafter, when the tower did separate from the capsule, Carpenter "felt a bigger jolt than at staging." He

watched the tower cartwheel lazily toward the horizon, smoke trailing from its three rocket nozzles.[79]

Sustainer engine cutoff came only as a gentle drop in acceleration. Two bangs were cues that the clamp-ring explosive bolts had fired and that the posigrade rockets had propelled the spacecraft clear of the booster. Now *Aurora 7* was on its own and in space. Becoming immediately aware that he was weightless, Carpenter elatedly reported that zero g was pleasant. Just as the capsule and booster separated, the astronaut had noticed that the capillary tube in his liquid-test apparatus seemed to fill. Then he averted his gaze; it was time to turn the spacecraft around to its normal backward flying orbital attitude. Since Glenn had left this maneuver to the automatic control system and the cost in fuel had been high, Carpenter used fly-by-wire. The spacecraft came smartly around at an expense of only 1.6 pounds of fuel, compared with over 5 pounds used on Glenn's MA–6 maneuver.[80]

As the capsule swung around from antenna-canister-forward to heatshield-forward, Carpenter was impressed by the fact that he felt absolutely no angular motion; his instruments provided the only evidence that the turnaround maneuver was being executed. Like Glenn, he was amazed that he felt no sensation of speed, although he knew he was traveling at orbital velocity (actually 17,549 miles per hour). Soon he had his first awe-inspiring view of the horizon—"an arresting sight," as he described it. Quickly checking his control systems, he found everything in order. Unknown to him, however, the horizon scanner optically sensing his spacecraft's pitch attitude was off by about 20 degrees. It was some time before he deduced this system was in error.

As Glenn had done, Carpenter peered out the window to track the spent Atlas sustainer engine. The tankage appeared to fall downward, as the engineers had predicted, and was tumbling away slowly. A trail of ice crystals two or three times longer than the launch vehicle streamed from its nozzle. Over the Canary Islands, Carpenter still could see the sustainer tagging along below the spacecraft. Meanwhile the astronaut continued to check the capsule systems and report his findings to the tracking sites. Over Kano, in mid-Nigeria, he said that he was getting behind in his flight plan because of difficulty in loading his camera with the special film to photograph the Earth-horizon limb. Before he moved beyond radio range of Kano, however, he managed to snap a few photographs. Although it was now almost dusk on his first "45-minute day," Carpenter was becoming increasingly warm and began adjusting his suit-temperature knob.[81]

Over the Indian Ocean on his first pass, Carpenter glanced down for a view through the periscope, which he found to be quite ineffective on the dark side of Earth. Concluding that the periscope seemed to be useless at night, he returned to the window for visual references. Even when the gyros were caged and he was not exactly sure of his attitude position, he felt absolutely no sensation of disorientation; it was a simple matter in the daylight to roll the spacecraft over and watch for a landmark to pop into view. Carpenter mentioned many recognizable land-

marks, such as Lake Chad, Africa, the rain forests of that continent, and Madagascar. But he was a little surprised to find out that most of Earth when seen from orbit is covered by clouds the greater part of the time.[82]

While over the Indian Ocean, Carpenter discovered that his celestial observations were hampered by glare from light seepage around the satellite clock inside the capsule. The light from the rim of the clock, which should presumably have been screened, made it hard for him to adjust his eyes to night vision. To Slayton at the Muchea station, Carpenter reported that he could see no more stars from his vantage point in space than he could have seen on Earth. Also he said that the stars were not particularly useful in gaining heading information.[83]

Like his orbital predecessor, Carpenter failed to see the star-shell flares fired in an observation experiment. This time the flares shot up from the Great Victoria Desert near Woomera, Australia, rather than from the Indian Ocean ship. According to the plan, four flares of one-million candlepower were to be launched for Carpenter's benefit on his first orbit, and three more each on his second and third passes. On the first try the flares, each having a burning time of 1½ minutes, were ignited at 60-second intervals. At this time most of the Woomera area was covered by clouds that hid the illumination of the flares; the astronaut consequently saw nothing and the experiment was discontinued on the succeeding two passes, as weather conditions did not improve.[84]

Out over the Pacific on its first circuit, *Aurora 7* performed nicely. The Canton Island station received the telemetered body temperature reading of 102 degrees and asked Carpenter if he was uncomfortable at that temperature. "No, I don't believe that's correct," Carpenter replied. "I can't imagine I'm that hot. I'm quite comfortable, but sweating some." The medical monitors accepted Carpenter's self-assessment and concluded that the feverish temperature reading resulted from an error in the equipment. For the rest of the journey, however, the elevated temperatures persisted, causing the various communicators to ask frequently about Carpenter's physical status.[85]

The food Carpenter carried on his voyage was different from Glenn's which was of the squeeze-tube, baby-food variety. For Carpenter the Pillsbury Company had prepared three kinds of snacks, composed of chocolate, figs, and dates with high-protein cereals; and the Nestlé Company had provided some "bonbons," composed of orange peel with almonds, high-protein cereals with almonds, and cereals with raisins. These foods were processed into particles about three-fourths of an inch square. Coated with an edible glaze, each piece was packaged separately and stored in an opaque plastic bag. As he passed over Canton he reported that he had eaten one bite of the inflight food, which was crumbling badly. Weightless crumbs drifting around in the cabin were not only bothersome but also potentially dangerous to his breathing. Though he had been able to eat one piece, his gloved hands made it awkward to get the food to his mouth around the helmet microphones.[86] Once in his mouth, however, the food was tasty enough and easy enough to eat.

During the second orbit, as he had on the first, Carpenter made frequent capsule maneuvers with the fly-by-wire and manual-proportional modes of attitude control. He slewed his ship around to make photographs; he pitched the capsule down 80 degrees in case the ground flares were fired over Woomera; he yawed around to observe and photograph the airglow phenomenon; and he rolled the capsule until Earth was "up" for the inverted flight experiment. Carpenter even stood the capsule on its antenna canister and found that the view was exhilarating. Although the manual control system worked well, the MA–7 pilot had some difficulty caging the attitutude gyros to zero before inverting the spacecraft. On two occasions he had to recycle the caging operation after the gyros tumbled beyond their responsive limits.

Working under his crowded experiment schedule and the heavy manual maneuver program, on six occasions Carpenter accidentally actuated the sensitive-to-the-touch, high-thrust attitude control jets, which brought about "double authority control," or the redundant operation of both the automatic and the manual systems. So by the end of the first two orbits Carpenter's control fuel supply had dipped to about 42 percent in the manual tanks and 45 percent in the automatic tanks. During his second orbit, ground capsule communicators at various tracking sites repeatedly reminded him to conserve his fuel.

Although his fuel usage was high during the second circumnavigation, Carpenter still managed to continue the experiments. Just as he passed over the Cape, for example, an hour and 38 minutes from launch, Carpenter deployed the multicolored balloon. For a few seconds he saw the confetti spray, signaling deployment. Then, as the line lazily played out, he realized that the balloon had not inflated properly; only two of the five colors—orange and dull aluminum—were visible, the orange clearly the more brilliant. Two small, earlike appendages about six to eight inches each, described as "sausages," emerged on the sides of the partially inflated sphere. The movement of the half-inflated balloon was erratic and unpredictable, but Carpenter managed to obtain a few drag resistance measurements. A little more than a half hour after the balloon was launched, Carpenter began some spacecraft maneuvers and the tether line twined to some extent about the capsule's antenna canister. Carpenter wanted to get rid of the balloon and attempted to release it going into the third orbit over the Cape, but the partially successful experimental device stayed doggedly near the spacecraft.[87]

As Carpenter entered the last orbit, both his automatic and manual control fuel tanks were less than half full. So *Aurora 7* began a long period of drifting flight. Short recess periods to conserve fuel had occurred earlier in the flight, but now Carpenter and his ship were to drift in orbit almost around the world. Although his rapidly depleting fuel supply had made the drift a necessity, this vehicle control relaxation maneuver, if successful, would be a valuable engineering experiment. The results would be most useful in planning the rest and sleep periods for an astronaut on a longer Mercury mission. Carpenter enjoyed his floating orbit, observing that it was a simple matter to start a roll rate of per-



## Flight of Aurora 7 May 24, 1962

*Mission Planning Conference (left), including, left to right, Kenneth S. Kleinknecht, Walter C. Williams, Christopher C. Kraft, Jr., Carpenter, and Robert D. Mercer. Carpenter ready to enter* Aurora 7 *(lower left). The launch (below).*











*Recovery by helicopter (left). Postflight checkup onboard the* Intrepid *(above).*

haps one degree per second and let the capsule slowly revolve as long as desired. *Aurora 7* drifted gracefully through space for more than an hour, or almost until retrofire time.

While in his drifting flight, Carpenter used the Moon to check his capsule's attitude. John Glenn had reported some difficulty in obtaining and holding an absolute zero-degree heading. Carpenter, noting that the Moon appeared almost in the center of his window, oriented the spacecraft so that it held the Moon on the exact center mark and maintained the position with ease.[88]

During the third orbital pass, Carpenter caught on film the phenomenon of the flattened Sun at sunset. John O'Keefe and his fellow scientists at Goddard had taught Carpenter that the color layers at sunset might provide information on light transfusion characteristics of the upper atmosphere. Carpenter furnished a vivid description of the sunset to the capsule communicator on the Indian Ocean ship:

> The sunsets are most spectacular. The earth is black after the sun has set. . . . The first band close to the earth is red, the next is yellow, the next is blue, the next is green, and the next is sort of a—sort of a purple. It's almost like a very brilliant rainbow. These layers extend from at least 90 degrees either side of the sun at sunset. This bright horizon band extended at least 90 degrees north and south of the position at sunset.

He took some 19 pictures of the flattened Sun.[89]

As Carpenter drifted over oceans and land masses, he observed and reported on the haze layer, or airglow phenomenon, about which Glenn had marveled. Carpenter's brief moments of airglow study during the second orbit failed to match the expectations he had derived from Glenn's reports and the Goddard scientists' predictions on the phenomenon. Having more leisure on his third circuit, Carpenter described the airglow layer in detail to Slayton at the Muchea tracking site:

> . . . the haze layer is very bright. I would say about 8 to 10 degrees above the real horizon. And I would say that the haze layer is about twice as high above the horizon as the bright blue band at sunset is; it's twice as thick. A star—stars are occluded as we pass through this haze layer. I have a good set of stars to watch going through at this time. I'll try to get some photometer readings. . . . It is not twice as thick. It's thinner, but it is located at a distance about twice as far away as the top of the band at sunset. It's very narrow, and as bright as the horizon of the earth itself.

The single star, not stars, that Carpenter tracked was Phecda Ursae Majoris, in the Big Dipper or Great Bear constellation, with a magnitude of 2.5.[90]

With each sunrise, Carpenter also saw the "fireflies," or "Glenn effect," as the Russians were calling it. To him the particles looked more like snowflakes than fireflies, and they did not seem to be truly luminous, as Glenn had said. The particles varied in size, brightness, and color. Some were gray, some were white, and one in particular, said Carpenter, looked like a helical shaving from a lathe. Although they seemed to travel at different speeds, they did not move out and

away from the spacecraft as the confetti had in the balloon experiment.

At dawn on the third pass Carpenter reached for a device known as a densitometer, that measured light intensity. Accidentally his gloved hand bumped against the capsule hatch, and suddenly a cloud of particles flew past the window. He yawed right to investigate, noting that the particles traveled across the front of the window from right to left. Another tap of the hand on the hatch sent off a second shower; a tap on the wall produced another. Since the exterior of the spacecraft evidently was covered with frost, Glenn's "fireflies" became Carpenter's "frostflies." [91]

Until *Aurora 7* reached the communication range of the Hawaiian station on the third pass, Christopher Kraft, directing the flight from the Florida control center, considered this mission the most successful to date; everything had gone perfectly except for some overexpenditure of hydrogen peroxide fuel. Carpenter had exercised his manual controls with ease in a number of spacecraft maneuvers and had made numerous and valuable observations in the interest of space science. Even though the control fuel usage had been excessive in the first two orbits, by the time he drifted near Hawaii on the third pass Carpenter had successfully maintained more than 40 percent of his fuel in both the automatic and the manual tanks. According to the mission rules, this ought to be quite enough hydrogen peroxide, reckoned Kraft, to thrust the capsule into the retrofire attitude, hold it, and then to reenter the atmosphere using either the automatic or the manual control system.[92]

The tracking site at Hawaii instructed Carpenter to start his preretrofire countdown and to shift from manual control to the automatic stabilization and control system. He explained to the ground station over which he was passing at five miles per second that he had gotten somewhat behind on the preretro checkoff list while verifying his hypothesis about the snowflake-like particles outside his window. Then as Carpenter began aligning the spacecraft and shifting control to the automatic mode, he suddenly found himself to be in trouble. The automatic stabilization system would not hold the 34-degree pitch and zero-degree yaw attitude. As he tried to determine what was wrong, he fell behind in his check of other items. When he hurriedly switched to the fly-by-wire control mode, he forgot to switch off the manual system. For about 10 minutes fuel from both systems was being used redundantly.[93]

Finally, Carpenter felt that he had managed to align the spacecraft for the retrofire sequence. The Hawaiian communicator urged him to complete as much of the checklist as possible before he passed out of that site's communications range. Now Alan Shepard's voice from the Arguello, California, station came in loud and clear, asking whether the *Aurora 7* pilot had bypassed the automatic retroattitude switch. Carpenter quickly acted on this timely reminder. Then the countdown for retrofire began. Because the automatic system was misbehaving, Carpenter was to push the button to ignite the solid-fuel retrorockets strapped to the heatshield. About three seconds after Shepard's call of "Mark! Fire One," the first

rocket ignited and blew. Then the second and the third followed in reassuring succession. Carpenter saw wisps of smoke inside his cabin as the rockets braked him out of orbit.[94]

Carpenter's attitude error was more than he estimated when he reported his attitude nearly correct. Actually *Aurora 7* was canted at retrofire about 25 degrees to the right, and thus the reverse thrust vector was not in line with the flight path vector. This misalignment alone would have caused the spacecraft to overshoot the planned impact point by about 175 miles. But the retrorockets began firing three seconds late, adding another 15 miles or so to the trajectory error. Later analyses also revealed a thrust decrement in the retrorockets that was about three percent below nominal, contributing 60 more miles to the overshoot. If Carpenter had not bypassed the automatic retroattitude switch and manually ignited the retrorockets he could have overshot his pickup point in the Atlantic by an even greater distance.[95]

Unlike Glenn, Carpenter had no illusion that he was being driven back to Hawaii at retrofire. Instead he had the feeling that *Aurora 7* had simply stopped and that if he looked toward Earth he would see it coming straight up. One glance out the window, however, and the "impression was washed away." [96] The completion of retrofire produced no changes the pilot could feel until his reentry began in earnest about 10 minutes later.

After the retrorockets had fired, Carpenter realized that the manual control system was still on. Quickly he turned off the fly-by-wire system, intending to check the manual controls. Although the manual fuel gauge read six percent left, there was, in fact, no fuel and consequently no manual control. So Carpenter switched back to fly-by-wire. At that time the automatic system supply read 15 percent, but the astronaut wondered how much really remained. Could it be only about 10 percent? With this gnawing doubt and realizing that it was still 10 minutes before .05-g time, Carpenter kept hands strictly off for most of his drifting glide. Whatever fuel there was left must be saved for the critical tumble. This 10-minute interval seemed like eternity to the pilot. The attitude indicators appeared to be useless, and there was little fuel to control attitude anyway. The only thing he trusted for reference was the view out of the window; using fly-by-wire sparingly he tried to keep the horizon in view. Although concerned about the fuel conservation problem, Carpenter gained some momentary relief from the fascinating vistas below: "I can make out very, very small—farm land, pasture land below. I see individual fields, rivers, lakes, roads, I think. I'll get back to reentry attitude." [97]

Finally, *Aurora 7* reached the .05-g acceleration point about 500 miles off the coast of Florida. As he began to feel his weight once again, Carpenter noted that the automatic fuel needle still read 15 percent. Within seconds the capsule began to oscillate badly. A quick switch to the auxiliary damping mode steadied the spacecraft. Grissom, the Cape communicator, reminded him to close his faceplate.[98]

*Aurora 7* was now in the midst of its blazing return to Earth. Carpenter heard the hissing sounds reported by Glenn, the cues that his ship was running into aerodynamic resistance. Immediately the capsule began to roll slowly, as programmed, to minimize the landing point dispersion. Carpenter looked out the window for the bright orange glow, the "fireball," as Glenn had described it, but there was only a moderate increase in light intensity. Rather than an orange glow, Carpenter saw a light-green glow apparently surrounding the cylindrical section. Was this radiant portion of the spacecraft ablating? Was the trim angle correct? The evenness of the oscillations argued to Carpenter that the trim angle was good. All the way through this zone Carpenter kept talking. Gradually it became difficult to squeeze the words out; the heaviest deceleration load was coming. The peak g period lasted longer than he had expected, and it took forceful breath control to utter anything.[99]

The automatic fuel tank on *Aurora 7* was emptied between 80,000 and 70,000 feet. As the plasma sheath of ionized air enveloped his spacecraft, communication efforts with Carpenter became useless, but the telemetered signals received by the radar stations at the Cape and on San Salvador predicted a successful reentry. The oscillations were increasing as the capsule approached the 50,000-foot level. *Aurora 7* was swinging beyond the 10-degree "tolerable" limits. Carpenter strained upward to arm the drogue at 45,000 feet, but he forced himself to ride out still more severe oscillations before he fired the drogue parachute mortar at 25,000 feet. The chute pulsed out and vibrated like thin, quivering sheets of metal. At 15,000 feet Carpenter armed the main parachute switch, and at 9500 feet he deployed the chute manually. The fabric quivered, but the giant umbrella streamed, reefed, and unfurled as it should. The rate of descent was 30 feet per second, the exact design specification. The spacecraft landing bag deploy was on automatic. Carpenter listened for the "clunk," heard the heatshield fall into position, and waited to hit the water. *Aurora 7* seemed to be ready for the landing, and the recovery forces knew within a few miles the location of the spacecraft as radar tracking after retrofire had given and confirmed the landing point.[100]

Splashdown was noisy but less of a jolt than the spaceman had expected. The capsule, however, did not right itself within a minute as it was supposed to do. Carpenter, noticing some drops of water on his tape recorder, wondered if *Aurora 7* was about to meet the fate of *Liberty Bell 7*, and then sighed in relief when he could find no evidence of a leak. He waited a little longer for the spacecraft to straighten up, but it continued to list to his left. Grissom's last transmission from Mercury Control had told Carpenter that it would take the pararescue men about an hour to reach him, and the astronaut realized that he had evidently overshot the planned landing zone. When he failed to raise a response on his radio, he decided to get out of the cramped capsule. Then he saw that the capsule was floating rather deeply, which meant that it might be dangerous to remove the hatch. Sweating profusely in the 101-degree temperature of the cabin, he pulled off his helmet and began the job of egress as it had been originally planned. Car-

penter wormed his way upward through the throat of the spacecraft, a hard, hot job made bearable by his leaving the suit circuit hose attached and not unrolling the neck dam. He struggled with the camera, packaged life raft, survival kit, and kinky hose before he finally got his head outside.

Half out of the top hatch, Carpenter rested on his elbows momentarily, released the suit hose but failed to deploy the neck dam and lock the hose inlet, and surveyed the sea. Lazy swells, some as high as six feet, did not look too forbidding. So he carefully laid his hand camera on top of the recovery compartment, squeezed out of the top, and carefully lowered himself into the water, tipping the listing spacecraft slightly in the process. Holding onto the capsule, he was able to easily inflate the life raft—upside down. By this time, feeling some water in his boots, he secured the hose inlet to the suit. He then held on to the spacecraft's side and managed to flip the raft upright. After crawling onto the yellow raft, he retrieved the camera, unrolled the suit neck dam, and prepared to wait for as long as it took the recovery searchers to find him. The recovery beacon was operating and the green dye pervaded the sea all around him.[101]

The status of Carpenter and *Aurora 7* was unknown to the public. Everyone following the flight by radio or television knew that the spacecraft must be down. But was the pilot safe? What the public did not know was that one P2V airplane had received the spacecraft's beacon signal from a distance of only 50 miles, while another plane had picked up the signal from 250 miles. *Aurora 7*'s position was well known to the recovery forces in the area. About eight minutes before the spacecraft landed, an SA–16 seaplane of the Air Force Air Rescue Service had taken off from Roosevelt Roads, Puerto Rico, for the radar-predicted landing point. Three ships—a Coast Guard cutter at St. Thomas Island, a merchantman 31 miles from the plotted point, and the destroyer *Farragut* about 75 miles away to the southwest—were in the vicinity of the impact point. But it would certainly take longer than an hour for any recovery unit to reach the site. Since Carpenter's raft had no radio, the drama was heightened. What exactly had happened to Carpenter after his landing was known only to the astronaut and perhaps to a few sea gulls and sea bass.[102]

Carpenter settled down on his raft and waited patiently for his rescuers. He mused over some seaweed floating nearby and "a black fish that was just as friendly as he could be—right down by the raft." In time, 36 minutes after splashdown, he saw two aircraft, a P2V and, unexpectedly, a Piper Apache. The astronaut watched the planes circle, saw that the Apache pilot was photographing the area, and knew that he had been found. Twenty minutes later several SC–54 aircraft arrived, and one dropped two frogmen, but Carpenter, watching other planes, did not see them bail out.[103]

Airman First Class John F. Heitsch, dropping from the SC–54 transport about an hour and seven minutes after Carpenter had first hit the water, missed the life raft by a considerable distance. Releasing his chute harness, he dove under

the waves and swam the distance to the side of Carpenter's raft. "Hey!" called the frogman to the spaceman. Carpenter turned and with complete surprise asked, "How did you get here?" Shortly thereafter a second pararescue man, Sergeant Ray McClure, swam alongside and clutched the astronaut's raft. The two frogmen quickly inflated two other rafts and locked them to the spacecraft. McClure and Heitsch later described the astronaut as smiling, happy, and not at all tired. The pilot broke out his survival rations and offered some to the two Air Force swimmers, who declined the space food but drank some space water.[104]

The three men, still without radio contact, perched on the three rafts and watched the planes circling above. One plane dropped the spacecraft flotation collar, which hit the water with a loud bang, breaking one of its compressed-air bottles. The swimmers retrieved and attached the flotation collar with only its top loop inflated and then crawled back onto their rafts. Shortly a parachute with a box at the end came floating lazily down some distance from the spacecraft. The men on the rafts supposed this was the needed radio, and one of the frogmen swam a considerable distance to get it. He returned with the container, opened it, and found that there was no radio inside, only a battery. Later Carpenter laughingly declined to repeat the swimmer's heated remarks.[105]

The Air Force SA–16 seaplane from Roosevelt Roads arrived at the scene about an hour and a half after the spacecraft landed in the Atlantic. To the SA–16 pilot the sea seemed calm enough to set his craft down upon and pick up the astronaut, but the Mercury Control Center directed the seaplane not to land. As later depicted by the news media and thoroughly discussed in Congress, this delay grew out of traditional rivalry between the Air Force and the Navy. Brigadier General Thomas J. Dubose, a former commander of the Air Rescue Service, wrote to Florida's United States Senator Spessard L. Holland, charging that Carpenter floated in the raft an hour and 20 minutes longer than was necessary. D. Brainerd Holmes, a NASA official, testified at the hearings that Admiral John L. Chew, commander of the Project Mercury recovery forces, feared the seaplane might break apart if it landed on the choppy waters. Because of this, according to Holmes, the decision had been made to proceed with helicopter and ship pickup as originally planned.[106]

After three hours of sitting on the sea in his raft, Carpenter was picked up by an HSS–2 helicopter, but either the rotorcraft settled as a swell arose or the winch operator accidentally lowered away, and the astronaut was dunked. Up went his arm and the hand holding the camera to keep the precious film dry. With nothing else amiss, Carpenter was hoisted aboard the helicopter, a drenched but happy astronaut. Richard A. Rink, a physician aboard, described Carpenter as exhilarated. The astronaut draped one leg out of the helicopter and, by cutting a hole in his sock, drained most of the water from his pressure suit. He then stood up and proceeded to pace around, sometimes settling in a seat, and intermittently talking about his flight. Carpenter arrived aboard the carrier *Intrepid* some four hours and 15 minutes after his return to Earth. The medical



*Carpenter and his wife are greeted in big Denver parade.*

**Aurora 7**
**Aftermath**



*Following visit to White House. Carpenter (right) and Walter C. Williams (center) receive in New York at the Waldorf-Astoria, along with former Presidents Hoover and Truman.*

examinations began immediately but were interrupted when the astronaut was called to the phone to receive what was by now President Kennedy's traditional congratulatory call. The President expressed his relief that Carpenter was safe and well, while Carpenter gave his "apologies for not having aimed a little better on reentry." From the *Intrepid* the astronaut was flown to Grand Turk Island, where, as Howard A. Minners, an Air Force physician assigned to Mercury, described it, Carpenter wanted to stay up late and talk.[107]

*Aurora 7*, picked up by the destroyer *Pierce*, was returned to Cape Canaveral the next day. When retrieved, the spacecraft was listing about 45 degrees compared to the normal 15 to 20 degrees, and it contained about 65 gallons of sea water, which would hamper the inspection and postflight analyses. Carpenter recalled two occasions on which the spacecraft had shipped small amounts of water, but he was unable to explain the larger amount found by the pickup crew. The exterior of the spacecraft showed the usual bluish and orange tinges on the shingles, several of which were slightly dented and scratched as after previous missions. Since there was no evidence of inflight damage, these slight scars presumably were the result of postflight handling. The spacecraft heatshield and main pressure bulkhead were in good condition except for a missing shield center plug, which had definitely been in place during reentry. Some of the honeycomb was crushed, resulting in minor deformation of the small tubing in that

area. Heitsch and McClure, the pararescue men, had reported the landing bag in good condition, but when it was hauled out of the water most of the straps were broken, probably by wave action. All in all, *Aurora 7* was in good shape and had performed well for Project Mercury's second manned orbital flight.[108]

The postflight celebrations and honors followed the precedents and patterns established by Glenn's flight. Administrator Webb presented to Carpenter and Williams NASA Distinguished Service Medals in a ceremony at the Cape. Carpenter also learned of Soviet Premier Nikita Khrushchev's cabled congratulations. Then the astronaut's hometown, Boulder, Colorado, gave him a hero's welcome. After being awarded a degree by the University of Colorado, where he had lacked a credit in a heat-transfer course, the astronaut facetiously commented that the blazing MA–7 reentry surely qualified him as a master in the field of thermodynamics. Memorial Day found the pilot in Denver, where a crowd of 300,000 people cheered and honored him. The next day he returned to work at Langley, where exhaustive technical debriefings were held to glean all the knowledge possible from MA–7.[109]

In these postflight sessions the astronaut insisted that he knew what he wanted to do at all times, but that every task took a little longer than the time allotted by the flight plan. Some of the equipment, he said, was not easy to handle, particularly the special films that he had to load into a camera. As a consequence he had been unable to get all the pictures the Weather Bureau had requested for its satellite photography program. Moreover, the flight plan that had been available during training was only a tentative one, and the final plan had been completed only a short while before he suited up for the launch. Carpenter felt that the completed plan should be in the astronaut's hands at least two months before a scheduled flight and that the flight agenda should allow more time for the pilot to observe, evaluate, and record. When asked about fuel consumption by the high thrusters, Carpenter replied that the 24-pounders were unnecessary for the orbital phase of a flight.

The astronaut recommended that some method be devised for closing off the high thrusters while the automatic control system was in operation. He granted that on the fly-by-wire, low-thruster operation, the spacecraft changed its attitude slowly, as was shown by the needle movement, and that the pilot would have to wait momentarily to pick up the desired attitude change rate. For tracking tasks, however, the manual-proportional mode served well; attitude changes could be made with only a gentle touch of the handcontroller. Talking with newsmen after the flight, Carpenter assumed full responsibility for his high fuel consumption. He pointed out, however, that what he had learned would be valuable for longer Mercury missions.[110]

As mid-year 1962 approached, Project Mercury faced yet another crossroad. Had enough been learned during the two three-orbit flights to justify going on to longer missions? Joe W. Dodson, a Manned Spacecraft Center engineer, speaking before the Exchange Club of Hampton, Virginia, indicated that the MSC designers

and planners and the operations team were well pleased with the lessons derived from Glenn, from Carpenter, and from their spacecraft. They were pleased especially at how well the combination of man and machine had worked.

Shortly thereafter, the press began to speculate that NASA might try a one-day orbital flight before 1963. Administrator Webb, however, sought to scotch any premature guesswork until Gilruth and his MSC team could made a firm decision. He stated that there might well be another three-orbit mission, but added that consideration was being given to a flight of as many as six orbits with recovery in the Pacific. Robert C. Seamans, Jr., NASA's "general manager," told congressional leaders that if a decision had to be made on the day on which he was speaking, it would probably be for another flight such as Glenn and Carpenter had made. But many members of Congress wanted to drop a third triple-orbit mission in favor of a flight that would come closer to or even surpass Gherman Titov's 17-orbit experience.

On June 27, 1962, NASA Headquarters ended the speculation by announcing that Walter Schirra would pilot the next mission for as many as six orbits, possibly by the coming September, with L. Gordon Cooper as alternate pilot.[111] The original Mercury objectives had been met and passed; now it was time to proceed to new objectives—longer missions, different in quality as well as quantity of orbits. Project Mercury had twice accomplished the mission for which it was designed, but in so doing its end had become the means for further ends.

# XIV

## Climax of Project Mercury

WALTER M. Schirra, a naval aviator who had won the Distinguished Flying Cross for his combat missions over Korea, received his most important assignment to date on July 27, 1962. It was the flight plan for Mercury-Atlas 8, a six-orbit flight that was to qualify the spacecraft and man's endurance for an extended spatial mission. A new plan, revised slightly for yaw-reference experiments using the periscope, was delivered on August 8. This was almost 60 days before the mission, allowing the period for training that Scott Carpenter had recommended. Carpenter had received his MA–7 document late, and major revisions had been inserted almost until launch day. Although Schirra's flight plan was altered in September, it did escape a thorough last-minute rewrite.

MA–8 was to be an engineering flight, in contrast with the exploratory nature of Glenn's flight in MA–6 and the developmental and scientific nature of MA–7. Schirra was expected to concern himself largely with the management and operation of the spacecraft's systems to conserve hydrogen peroxide attitude control fuel and electrical power. The MSC planners had examined the minute-by-minute details from launch to recovery in the interest of spacecraft endurance and had programmed only a few experiments that would require fuel or electrical power. The pilot was to try to observe a ground xenon light of 140-million candlepower at Durban, South Africa, and four flares of 1-million candlepower each that would be launched near Woomera, Australia. The only other experiment requiring astronaut participation included some weather and terrestrial photography as the pilot sighted targets of opportunity. Besides these experiments, several passive test devices were superimposed on the spacecraft's exterior. Eight ablation panels, consisting of several types of material, were fused onto the afterbody's beryllium shingles, and a white paint patch was brushed on the capsule's side for still more evaluations of spatial thermal effects on various materials.[1]

Early in August, Schirra trained energetically for a targeted September launch; spacecraft No. 16 was almost ready for a simulated flight in Hangar S; and Atlas No. 113–D had arrived at the Cape. Then on August 11, the Soviet Union, with-

out prior announcement, launched *Vostok III*. NASA leaders, who had endured much needling on the space gap since Gherman S. Titov's 17-orbit flight, a little more than a year earlier, grimly read the press reports. The five-ton Vostok spacecraft, with Major Andrian G. Nikolayev aboard, was in an orbit with a 156-mile apogee and a 113-mile perigee, inclined (as usual for Vostoks) at 65 degrees.

The "gap" seemed to become a "gulf" the following day, when *Vostok IV*, carrying Lieutenant Colonel Pavel R. Popovich, shot into an orbit with an apogee of 157 miles and a perigee of 112 miles. Soon after the second launch, Nikolayev reported that he had sighted Popovich's spacecraft. Western tracking stations variously reported that the two craft were as close as 3 and as far as 300 miles apart. Intercepted communications between Nikolayev (code-named Falcon) and Popovich (Golden Eagle) caused serious speculation that the Vostoks might try to rendezvous, but apparently no such attempt was made.

On August 15, Nikolayev landed after 64 orbits and more than 95 hours in space. Popovich touched down six minutes later, after 48 orbits and more than 70 hours' flight.[2] The U.S. decision to accelerate the space program called for by President Kennedy in May 1961 seemed more than validated to most critical observers. Meanwhile engineers who were designing what became the Gemini vehicle for rendezvous with an orbiting Agena rocket studied the possibility of adding a space-maneuvering capability to Mercury. On August 24, Kenneth S. Kleinknecht, the Project Office chief, reported that such an innovation would require at least 400 pounds of additional spacecraft hardware and fuel. Upon hearing this, Christopher C. Kraft, Jr., the Mercury flight director, dourly observed that this added weight might dangerously degrade the capsule's chances of reaching orbit, but Robert R. Gilruth asked Kleinknecht to continue his studies. A few days later the Mercury Project Office and the Flight Crew Operations Division handed the MSC director a joint proposal for maneuvering an orbiting Mercury spacecraft close to a passive Echo-type satellite. But because of time, weight, and safety considerations, Gilruth and his management lieutenants rejected the proposal, abandoned the idea of a maneuverable Mercury spacecraft for the time being, and turned back to the more prosaic but essential business of preparing for the modest doubled-distance, six-orbit flight slated for Walter Schirra.[3]

## Longer Legs for Mercury

Specific planning for MA–8 had begun back in February during the technical debriefing of John Glenn following the MA–6 mission. While attending the Grand Turk Island meetings, Kleinknecht and Donald K. Slayton had agreed that a flight of six or seven orbits seemed to be a logical intermediate step from the three-pass flight of Glenn toward an ultimate 18-orbit goal then under study. When Kleinknecht returned to his office (then at Langley) he put his staff to work in conjunction with John F. Yardley's group of McDonnell engineers on the changes necessary to accomplish a seven-orbit Mercury flight.[4]

The staff's problem was to appraise the spacecraft components' lifetime in terms of the ability of each system to perform two or three times longer than the operating limits originally built into them. Flight rules so far had specified an almost continuous operation of the automatic stabilization and control system, which caused a heavy drain on the spacecraft's electrical power supply. Also critical were oxygen reserves, reaction control fuel supplies, and increased recovery requirements. The tracking and communications network, built for three-orbit coverage, would require extensive modification if the tracking criteria applied to three orbits should apply to six or seven.

The three-orbit Mercury spacecraft, with all its electrically powered systems in action, consumed about 7080 watt-hours of battery power from a total of about 13,500 watt-hours available. Thus a seven-orbit mission, obeying previous flight rules, would consume about 11,190 watt-hours, leaving a reserve supply of only 6.7 percent. Mercury Project Office engineers insisted there should be at least a 10 percent postlanding reserve as a safety factor and suggested at least two conservation methods to attain and surpass this amount. One was drawn from an earlier recommendation presented by McDonnell designers and planners; they had outlined possibilities for an 18-orbit mission, proposing that some of the systems be turned off during a substantial portion of the flight. In addition to this, the MSC engineers recommended switching telemetry transmitter and radar beacon operations to ground command. These measures, they felt, would raise the reserve power levels to about 15 percent.

After studying the spacecraft's environmental control system, the project engineers at MSC concluded that about 4.4 pounds of oxygen would be consumed during a seven-orbit flight, taking pilot usage and cabin leakage rates into consideration. By prevailing mission rules, this would leave an insufficient supply to meet possible contingencies of abnormal recovery. A supply of 8.6 pounds would meet the requirement, but the system carried only two 4-pound capacity bottles. So, either the rules had to be relaxed or the system had to be modified. The MSC study group recommended the modification possibility, adding that a strenuous program to reduce cabin leakage rates to 600 cubic centimeters per minute should be started. Formerly up to 1000 cubic centimeters had been within design specifications. To cover the increase in carbon dioxide production from the longer flight, the project office planners pointed out that the canister carried in the three-orbit spacecraft could be filled with lithium hydroxide to its 5.4 pound capacity. This amount represented an increase from the 4.6 pounds that had been carried on the three-pass flights and should be sufficient extension of the $CO_2$ removal capability.

At the same time that these efforts were being made to provide the spacecraft systems with all the power they needed and the astronaut with enough breathable oxygen, some NASA and McDonnell engineers were wrestling with more advanced problems of tripling, quadrupling, and even raising by factors of six and eight the capabilities of the Mercury spacecraft to orbit Earth. But at this stage, planning for the day-long, 18-orbit mission depended heavily on some positive proof

from MA–8 that man and machines could tolerate, over a longer period and with larger margins for pilot safety and mission success, the vacuous, weightless, hot-cold extremes of space.

The most critical problem in preparations for the extended mission was providing enough hydrogen peroxide fuel to power the capsule's reaction control system. A seven-orbit mission operating in the fully automatic control mode would consume about 28 pounds of fuel, providing the systems were functioning normally. The Mercury Project Office suggested alternating a combination of automatic and manual modes to provide safer fuel reserves at the end of the flight. Such a procedure would expend 23 pounds of automatic and 18 pounds of manual fuel, leaving reserves of 12 and 15 pounds, respectively. Then, in case of malfunction in one of the control modes, the astronaut would be assured of an adequate fuel supply in the other mode.

Recovery procedures changed considerably for the proposed seven-orbit mission. The fourth, fifth, sixth, and seventh sinusoidal curves of the orbital ground trace passed over geographical points that almost intersected, while the fifth and sixth orbits did intersect in the northern Pacific about 275 miles northeast of Midway Island. This pattern shifted to the Pacific Ocean the optimum recovery area that had been in the Atlantic for MA–4 through MA–7. Kleinknecht's staff pointed out that a once-an-orbit primary recovery capability could be maintained with only a slight increase in the recovery forces. The primary landing area during the seventh orbit could be covered easily by Navy vessels moving to the zone from their base at Pearl Harbor, but some of the aircraft staging bases for past contingency landing areas would have to be relocated.

Then Sigurd A. Sjoberg, Robert F. Thompson, and other mission and recovery planners discovered a slight flaw in the seven-orbit flight profile. A hard mission rule required a contingency recovery capability within 18 hours after landing. This requirement could be easily met for a six-orbit mission, but adding a seventh orbit required additional recovery forces to satisfy that mission rule. So NASA decided to make MA–8 a six-orbit flight.[5]

During August 1962 the MA–8 mission planners continued to wrestle with many other operational considerations. But within the month they were able to issue the mission rules, data acquisition plan, a slight revision to the flight plan, recovery requirements and procedures, and the mission directive, only to find on some occasions that closer study of engineering preparations revealed new constraints, requiring minor changes to most of their guidebooks.[6]

## Preparations for MA–8

While the long-duration mission studies were in progress and the mission rules and directives were being prepared and issued, other personnel of the NASA-military-industry complex were readying the spacecraft, booster, and recovery forces. The astronaut and alternate pilot were in intensive training.

The Manned Spacecraft Center allocated spacecraft Nos. 16 and 19 for the six-orbit mission, with No. 16 as the preferred vehicle. No. 16 had arrived at Cape Canaveral in January 1962, while No. 19 had followed two months later. Rework to incorporate a six-orbit capability was done at the Cape by the MSC Preflight Operations Division with the help of McDonnell technicians. The work and testing began slowly but were well underway in April. In that month temperature surveys at the critical points on the capsule were completed, the environmental control system passed its altitude-chamber tests, and the reaction control system was exercised satisfactorily. Minor troubles cropped up, as usual. Emergency oxygen rate valves stuck. Water coolant flowed too freely. The cabin's oxygen leakage rate was too high. Each difficulty slowly was overcome, but it became evident that a hoped-for August launching might slip at least a month.[7]

The Mercury Project Office had pronounced 5.4 pounds of lithium hydroxide sufficient for oxygen purification for the MA–8 mission, but the MSC Life Systems Division personnel checking this theory found the absorbers unsatisfactory. Canisters containing 4.6 pounds of the mixture had been used in the three-orbit spacecraft and tests showed that this amount of the chemical functioned to keep the air breathable for 34.5 hours before carbon-dioxide levels rose too high. Then canisters supposedly containing 5.4 pounds of absorbent were tested, with both fixed and variable inputs of heat, water vapor, and carbon dioxide, and with a human subject breathing the oxygen. To the amazement of the testers, the lifetimes of these canisters averaged only slightly higher than those that were partly filled.

Then it occurred to somebody in the division to weigh the canisters. Each proved to have been packed about half a pound short. Finally the completely filled canisters were tested for as long as 71 hours before breaking down, demonstrating that the original design met the development demands, after all. Well-filled absorbers would qualify for a day-long mission as well as for six orbits.[8]

As the work continued at the Cape on spacecraft No. 16, Scott Carpenter made his fuel-thirsty, three-orbit flight on May 24. During *Aurora 7*'s postflight analysis MSC engineers, including G. Merritt Preston's checkout crew, took new and closer looks at the attitude and reaction control systems. They decided that attitude thrusters slightly different in design would have to be installed in the MA–8 spacecraft. While Preston's men were implementing this decision, they also managed to get No. 16's cabin oxygen leakage rate down to a highly satisfactory 460 cubic centimeters per minute, although in the weeks ahead this rate would rise slightly.[9]

Other results from MA–7, as recorded from telemetry data, as reported by Carpenter, and as revealed by examination of flight-tested *Aurora 7*, had intensified the flurry of activity all along the line to prepare No. 16 for its flight. Carpenter had many suggestions regarding spacecraft configuration. The heavy periscope, he said, was useless on Earth's nightside; the window alone could be used to find the spacecraft's attitude. The determined workers for spacecraft weight re-

duction were delighted to hear this assessment. But the MA–7 postflight inspection team reported that Carpenter's landing error had been caused by a faulty yaw attitude, largely because Carpenter had performed a final control systems check just prior to retrofire and had used the window mainly as his chief yaw reference. Could the window and the pilot be trusted? the Mercury team wondered. Would the periscope have assisted in correcting the attitude and the resultant overshoot? The only way to find out the answers was to fly the periscope again.[10]

So for MA–8 the periscope became, in a sense, an experimental instrument. Using both the periscope and the window for spacecraft attitude reference, Schirra would check the position of his capsule carefully on Earth's day and night sides. Then he would check his visual judgment to gauge attitude, comparing his ability against the scope and instrument readings.

Having decided to retain the periscope, the mission planners and Cape preparations team for MA–8 butted into fresh difficulties. The experiment schedule had called for an ultraviolet airglow spectrograph to be put in the periscope's well. This spectrograph had been developed through the intensive work of Albert Boggess, III, at the Goddard Space Flight Center upon the request of the NASA Headquarters Ad Hoc Committee on Scientific Tasks and Training for Man-in-Space. Now the decision to carry the periscope forced the withdrawal of the experiment, creating some disappointment among NASA's scientifically interested personnel. Even the implementation of this decision turned out to be somewhat of a problem. Preston's men tried to use the periscope from the alternate spacecraft (No. 19) but found it to be defective. By the end of August they managed to install a standard periscope, "cannibalized" from spacecraft No. 15.[11]

Carpenter, the second astronaut to land with empty fuel tanks in the manned orbital program, also suggested that a control-mode selector switch be integrated with the control system to seal off the high thrusters until they were needed for fast reaction maneuvers. The Project Office approved, and this fuel-saving switch was installed in the MA–8 spacecraft.[12]

Aside from these and other minor modifications spacecraft No. 16 was a duplicate of *Aurora 7*. Many of the technical changes were aimed at weight reduction, fuel conservation, and adding extra supplies for a longer mission. Deletions included the astronaut-observer camera, one of two redundant command receiver-decoders, and the high-frequency voice transceiver. To increase pilot comfort and save weight, the preflight preparations crew extracted the lower leg section of the couch and substituted toe, heel, and knee restraints. During the orbital phase of the mission, the knee restraints could be loosened. An extra 15 pounds of coolant water and an improved fastening technique for the heatshield center plug completed the list of additions.[13]

While the engineers were working, Astronaut Schirra proceeded through the most efficient flight training program yet undertaken. Except for added yaw-recognition displays, he used the same procedures trainers that his predecessors

had used; having a definite flight plan, he could practice on his own specific mission profile. He was able to work through his simulated retrofire and reentry tasks in the Langley procedures trainer before the device was dismantled for shipment to Houston. And for personal physical conditioning, he often went swimming and water skiing.[14]

Late in July, Preston reported that the work schedule for spacecraft No. 16 was aimed at a September 18 launch date. When the flight preparation crews added a sixth day to their work week to compensate for various delays, the MSC managers remained optimistic.[15]

Some worry among the mission planners had been injected in July when Project Dominic, an Atomic Energy Commission (AEC) high-atmosphere nuclear test over the Pacific, had created a new zone of radiation, lower than the Van Allen belts. In the face of this possible threat to an orbiting man, AEC, NASA, and McDonnell carefully studied a number of satellite and probe launchings in August designed to explore the belt. After the solar batteries of several satellites failed—including *Ariel I,* the world's first international satellite project, which developed operational difficulties probably attributable to Dominic—the investigators reported that the new radiation circled Earth at the geomagnetic equator and was about 400 miles wide and 4000 miles deep. Sounding rockets by telemetry data indicated rapid and continuing decay of radioactivity in the corridors of the next Mercury mission. By the end of August the radiation hazards seemed negligible. The MSC engineers, distrusting the reports that all danger had disappeared, installed a radiation dosimeter on the spacecraft hatch, provided the pilot with a hand-held model, and attached four more to Schirra's pressure suit.[16] The hand-held model could provide real-time indications during the flight.

Besides some labor-management difficulties that momentarily hampered the activities of the aerospace industry at this time, the booster for MA–8 contributed its share of troubles. Atlas 113–D was to have been delivered to Cape Canaveral toward the end of July, but it failed its initial composite test at the San Diego factory. Finally it was shipped on August 8. Then the Air Force, revealing that its Atlas program had suffered four recent turbopump failures, advised the Manned Spacecraft Center that No. 113–D would be put through a flight-readiness static firing. Since the MA–8 launch vehicle would be the first one in the Mercury program not having the two-second post-ignition hold-down time, the Air Force felt the static firing to be an important requirement.

A one-week slippage was now added. But before the test could be made, the Air Force and Convair inspectors found a fuel leak in a seam weld on the booster. Calculating the time required for work to be done, on September 6 the Mercury-Atlas launch operations committee rescheduled the mechanical and electrical matings of spacecraft and booster and three planned simulated flights. These tests would continue through September 24, making October 3 the most likely day for the MA–8 launch.



**MA–8**
**Preflight**

*At the Cape, Schirra closely watches the mating of spacecraft and booster.*



*Schirra checks his spacecraft camera equipment with Paul Backer of McDonnell, left, and Roland Williams of RCA.*




*Underscoring Schirra's test-pilot-like concern for his equipment is this Raytheon Corporation cartoon.*

Atlas 113–D actually differed little from its predecessors in the manned flight program. It incorporated a dozen or so technical changes from the 107–D configuration that had propelled Carpenter into orbit. The fuel tank insulation had been removed as a solution to some of the difficulties that had beset John Glenn's booster (Carpenter's launch vehicle had retained the insulation). More important, baffled fuel injectors (which had been found in static firing tests to virtually eliminate the possibility of combustion instability) and the accompanying hypergolic ignition (in which fuel and oxidizer ignite on contact) were added to 113–D. These innovations, therefore, eliminated the two-second hold-down at ignition, saved fuel, made for smoother initial combustion, and provided a safer liftoff.[17]

The tracking network for MA–8 was augmented by five airborne relay stations, in the form of five Air Force C–130s, to cover areas that otherwise would have been out of communications range of the ground sites. The C–130s, each equipped with ultra-high-frequency and very-high-frequency equipment for voice relay, were based at Patrick Air Force Base, Florida; Ramey Air Force Base, Puerto Rico; and Midway Island.[18] The mixed recovery force, deployed by the Department of Defense, included 19 ships in the Atlantic and nine in the Pacific. Aircraft numbering 134 of various types covered primary and secondary spacecraft landing areas. In all, about 17,000 men, including over 100 aeromedical monitors and specialists, made up the global MA–8 recovery forces.

Recovery commanders in the Pacific directed a training course in spacecraft and astronaut retrieval for appropriate teams, using boilerplate capsules, flotation collars, and other gear provided by MSC. Major General Leighton I. Davis and Walter C. Williams made an inspection tour to the Pacific to evaluate the training program and the overall recovery readiness picture. Later Kraft, reading their findings, reported that preparations and materials seemed "reasonably well" developed. But he was disappointed that NASA had been unable to enlist the support of another Navy radar ship equipped with FPS–16 equipment for C-band operation and thus had to rely on two S-band ships instead. Kraft felt that S-band radar, called "Verlort" for its 700-mile "very long range tracking" ability, was less reliable than the C-band.[19]

If recovery was to go smoothly, interservice misunderstandings like the one that had developed during Carpenter's rescue would have to be avoided. General Davis, the DOD military representative for Mercury support operations, had reported to Secretary of Defense Robert S. McNamara that the delay at Mercury Control in the decision to pick up Carpenter had stemmed partially from a lack of direct communication with the astronaut. To overcome this breakdown, the recovery room in the Control Center was modified to permit almost instantaneous communication between tracking stations and recovery forces; and Schirra's spacecraft was equipped with a long extension line, which would permit him to maintain voice contact even in the life raft. The extended period of suspense that climaxed Carpenter's mission should never happen again in Project Mercury.[20]

At this juncture, President Kennedy set out on a tour of the space centers of the South to inspect and show his interest not only in the preparations for MA–8 but also in the vast array of technological talents being mobilized for the accelerated space program, including the first lunar voyage. Kennedy flew down to Cape Canaveral to see the Merritt Island Launch Area that was being built for the huge Saturn V rockets. Then he went on to Houston to see the site for the management and control center on the Texas coastal prairie. Before a sweltering crowd half-filling the 72,000-seat Rice University stadium, the President spoke on September 12, 1962, in earnest defense of his proclaimed program for manned exploration of the Moon. "No man can fully grasp how far and how fast we have come," said Kennedy. "The exploration of space will go ahead, whether we join it or not. . . . It is one of the great adventures of all time, and no nation which expects to be the leader of other nations can expect to stay behind in the race for space. . . . We intend to be first. . . . to become the world's leading space-faring nation." The youthful President then addressed one of his memorable statements to those who had asked, "Why send a man to the Moon?"

> We set sail on this new sea because there is new knowledge to be gained and new rights to be won, and they must be won and used for the progress of all people. For space science, like nuclear science and all technology, has no conscience of its own. Whether it will become a force for good or ill depends on us, and only if the United States occupies a position of preeminence can we help decide whether this new ocean will be a sea of peace or a new, terrifying theater of war. . . . Space can be explored and mastered without feeding the fires of war, without repeating the mistake that man has made in extending his writ around this globe of ours.[21]

If President Kennedy's remarks in Houston, later at the McDonnell factory in St. Louis, and elsewhere, proved an accurate reflection of most Americans' sentiments about the space program, his words persuaded few of the vocal economic, political, and scientific conservatives who were watching costs soar along with the engineering effort. The NASA space budget alone for this fiscal year was over $5 billion, which represented a tax of about 40 cents on each American per week; but the Nation was prosperous, the economy seemed sound, and critics of the "space circus" were seldom heard.

Toward the end of September, all mission preparations, the astronaut, the spacecraft, and the launch vehicle reached a high state of readiness. The spacecraft and the booster mated well; the simulated tests before mission ticked off without further hitches; and October 3 thus remained a promising launch date.

Schirra, viewing the elaborate preparation effort, studying his flight plan, and knowing that his mission involved the evaluation of the capsule's ability to accomplish a day-long flight, recognized the immensity of the engineering effort behind him. In honor of these labors, he selected the name *Sigma 7* for his spacecraft. "Since this was to be an engineering evaluation," he explained, the name chosen for capsule No. 16 was that of an engineering symbol for summation, Sigma,




*President John F. Kennedy, touring space facilities, spoke to 35,000 people in the stadium at Rice University, September 12, 1962: "We intend . . . to become the world's leading spacefaring nation."*

with the number seven added to it for the seven-member Mercury astronaut team. "Thus," he said, "was derived the name and symbol that was painted on the spacecraft, Sigma 7." [22]

On the final lap toward launch day, Schirra began a controlled diet on September 21; nine days later physician Howard A. Minners placed him on his low-residue diet. Schirra complained mildly while adjusting to the low-residue food, but in every other respect he was primed and ready, mentally and physically.

As always when flight day neared, the Mercury operations team through the Weather Bureau support group kept a watchful eye on existing weather disturbances in both the Atlantic and Pacific areas. About 400 miles north by northeast of Puerto Rico, tropical storm Daisy churned the waters of the Atlantic, while three typhoons, Dinah, Emma, and Frieda, whipped Pacific waves. On October 1, Walter Williams told the news corps covering the flight at the Cape that except for the weather "all elements of the MA–8 flight are in a go condition as of this time." By 5 p.m. the following day, Williams was satisfied with the chances for success and decided to launch as planned.[23]

Notified by Williams that he had a 7 o'clock liftoff "appointment" the next morning, Schirra dined leisurely and retired early. Without any sleep-inducing medications, the pilot drifted into slumber shortly after 8 p.m. and got about five hours of sound rest. Minners roused Schirra at 1:40 a.m. to begin the precise readiness routine. The astronaut showered, shaved, and met with Gilruth, Williams, Slayton, and Minners for breakfast. He ate heartily the "astronaut launch-

ing breakfast," consisting of eggs, filet, dry toast, orange juice, and coffee, plus a portion of a bluefish that he had speared the day before. The major preflight physical having taken place two days earlier, Minners checked Schirra briefly, pronouncing him in excellent physical condition. After Minners applied the physiological sensors to the astronaut's body, Schirra signaled to Joe W. Schmitt to assist him in donning the silvery pressure suit. At a little past 4 o'clock, Schirra and his attending retinue emerged from Hangar S.

As Schirra headed for the transfer van, Alvin B. Webb, a veteran space-newsman assigned by the press pool to report activities in that area, observed that the astronaut seemed to be unusually relaxed and smiling, as compared to previous astronauts on their way to the launch pad. Seconds later, Schirra, carrying his portable air conditioner, climbed aboard the van for a leisurely ride toward the flood-lit spire in the distance. As the van reached the blockhouse and gantry complex, Byron G. MacNabb, representing the Convair-Atlas team, greeted Schirra and said: "On behalf of the crew of Pad 14, I wish you a successful flight and a happy landing." Acknowledging this salutation, Schirra boarded the elevator and moved up the gantry. At 4:41 a.m. the astronaut slid inside *Sigma 7*.[24]

## The Textbook Flight

As October 3, 1962, dawned, television viewers and radio listeners in the United States faced the day with a spectacular doubleheader in store: in the new "world series" in space, the orbiting of a third American; in the older World Series on Earth, the opening baseball game between the New York Yankees and the San Francisco Giants. Many dials switched later in the day to the traditional nine-inning sports event, but two of the three major networks continued to compete for the attention of Americans with minute-by-minute coverage of *Sigma 7*'s six orbits.[25]

Schirra slipped into his capsule, buckled himself comfortably in the couch, and smiled when he saw an automobile ignition key hanging from the handcontroller safety latch. This represented a tension breaker provided by the ground crew. Then he began to inventory his gear inside the cabin—flight-plan bar charts neatly placed in a slot just below the instrument panel, star charts arranged in a rack to his side, cameras in place, and accessories stowed in his ditty bag. When he stuck his hand in the glove compartment, he found some crinkly plastic wrapped around a soft object that turned out to be a steak sandwich. Otherwise, everything was as it should be, and Schirra began his prelaunch checkout tests.[26]

Outside the spacecraft, technicians busily bolted on the side hatch, and every bolt sank neatly in its threads. From there on, the countdown proceeded rapidly until about 6:15 (T minus 45 minutes), when the Canary Island station reported a malfunction in one of its radar sets. Since this equipment would be critical in ascertaining the orbital parameters, Williams quickly called a hold in the countdown. The Canary radar required only 15 minutes to be fixed and for the next 45 minutes the countdown ticked off with precision.

At 7:15 a.m., the engines of Atlas 113–D roared and the big booster rose from the pad to rocket Schirra and *Sigma 7* on their journey through space. "I have the lift-off," Schirra shouted into his microphone to Slayton in the Mercury Control Center, "and she feels real nice." Ten seconds above the pad, however, No. 113–D telemetered signals showing an unexpected clockwise roll. Both primary and secondary sensors inside the launch vehicle, monitoring such movements to determine the seriousness of the situation, registered a rifling roll only 20 percent short of an abort condition. Then, to the relief of the capsule and booster monitors in the control center, the threatening twist suddenly smoothed out. Schirra began transmitting the status of his supplies and systems' operation. After a little more than a minute, he realized that he seemed to be talking to himself. Glancing around the cockpit, he noted that evidently the noise associated with max q had incorrectly operated the sound-activated radio microphone, and so he pushed the button to talk to Slayton. Surely something should be done to obviate this problem, he thought, because he needed to keep his hand on the abort handle, or "chicken switch," rather than having to press the "talk" button manually.

Schirra listened for booster engine cutoff; it came two seconds earlier than programmed. He saw a flash of light and smoke reflected from the booster engines at the time the aft section parted from the sustainer. Seconds later the escape tower jerked away from the top of *Sigma 7,* its rocket blast spreading a spotty film on the window. Sustainer engine acceleration seemed slow, Schirra mused, but since his escape tower had "really said 'sayonara,' " he could only wait and see if the sustainer would burn long enough to accelerate him into orbit. Acceleration seemed to drive on and on, the pilot said, and finally the sustainer engine cut off, about 10 seconds late. Data registered on the control panels at the Cape indicated a 15-foot-per-second overspeed that would send Schirra higher—176 miles—and faster—17,557 miles per hour—than any other astronaut had gone or would go during Project Mercury.[27]

When *Sigma 7* parted from its Atlas rocket, Schirra turned on the auxiliary damping controls to eliminate the spacecraft quivers produced by the blast of the posigrade rockets. Although he dearly wanted to look out the spacecraft window at the scene below, Schirra fixed his eyes on the instrument panel, flipped his attitude control to the fly-by-wire mode, and started a leisurely four-degree-per-second cartwheel movement to obtain his correct orbital attitude position. Turnaround, which was deliberately slow to conserve fuel, used only three-tenths of a pound from a total supply of almost 59 pounds of hydrogen peroxide. To Schirra the thruster jets operated as if they had been programmed by a computer, providing tiny single pulse spurts to obtain exactly the position he desired.[28]

Now he could look out the window to track the sustainer tankage. Peering at a prescribed spot, Schirra saw the spent vehicle come into view in the upper left corner of his "picture" window, just as his predecessors had said it should. Glenn and Carpenter had mentioned that their tankage appeared to be silvery in color; to Schirra, his looked almost black, "with a white belly band of frost." The spent

launch vehicle seemed to have completed the same turnaround maneuver as the spacecraft, because Schirra looked down its nozzle. The *Sigma 7* pilot saw none of the ice crystals or contrails streaming from the tankage reported by Carpenter.

Schirra said that the fly-by-wire system that had been redesigned to use only the low thrusters, if desired, served well to adjust his attitude to track the spent sustainer. The thrusters responded crisply and cut off without residual reactions. Tracking the booster seemed even easier than following a target in an aircraft on an air-to-air gunnery problem. Schirra nevertheless knew that he had neither the attitude control and maneuvering thrust nor the computational ability to perform a rendezvous. There were simply too many conditions to be judged if he were to solve the orbital mechanics task so shortly after launching. Schirra later expressed the opinion that rendezvous with another vehicle in space appeared to be possible, but that he believed a pilot would have to have very precise attitude data to effect a coupling. He confirmed what students of celestial mechanics already knew, while providing them with a feel for the problems of perceiving relative motion. Differences in velocity of only 20 to 30 feet per second between two objects in space could be disastrous, he said.

As Schirra neared the Canary Islands, he turned aside from tracking the booster to check out the manual-proportional mode of spacecraft control. The pitching-up maneuver matched well with his experience on the procedures trainer. As Grissom had done before him in Mercury-Redstone 4, Schirra noted that he tended to overshoot his desired attitude position and that the manual mode of control seemed "sloppy" compared with the semi-automatic modes. Manual-proportional control clearly was not the best way to "park" the spacecraft in one attitude. A far better method, he learned, was to rely on fly-by-wire with low thrusters only.

Passing over Nigeria, Schirra transferred spacecraft control to the automatic stabilization and control system and busily monitored his panel dials. Minutes later he had traversed the African continent without yielding more than once to the temptation to watch the panorama passing beneath him. Moving toward Zanzibar, Schirra began to feel warm. He decided to devote full attention to this before somebody, as he said later in the postflight debriefing, started "jumping up and down in the control center" and yanked him out of orbit. Frank H. Samonski, the environmental control system monitor in the Mercury Control Center, had also watched the temperature rise. At Mercury Control the suit heat signal, creeping steadily upward, had indeed caused the ground controllers to think about terminating the mission after the first circuit. Samonski conferred with Charles A. Berry, who had relieved Stanley C. White as flight surgeon in the Control Center. Berry believed that the astronaut was in good condition. He advised trying a second orbit to see if the suit and its occupant could settle their temperature differences. Kraft, the flight director, listened to the two men and decided to give the go-ahead to Schirra for a second orbit. Wrestling with communications checks and with his suit temperature, he found himself halfway around the world before the Guaymas station relayed the official green light for his second orbit.

When the temperature problem first appeared, the control knob setting was at Position 4. Prior to the flight, Schirra had established a procedure for just this situation. Rather than rushing to a high setting, he slowly advanced the knob by half a mark at a time, then waited about 10 minutes to evaluate the change. Had the valve been advanced too quickly, the heat exchanger might have frozen and reduced its effectiveness even more. By the time Position 7 was reached, Schirra was much cooler and felt sure that his temperature problem was nearing resolution, but for good measure he turned to Position 8. Shortly he became a little cool, and Samonski recommended that he return to Position 3.5. Schirra, thinking that some kind of analysis had been performed in the Mercury Control Center, complied. Immediately noting that the temperature was rising again, he quickly returned the setting to 7.5 and left it alone for a while.

Rounding Muchea, Australia, on his first pass, Schirra had nosed the small end of *Sigma 7* down to watch for the first ground flare launch. He said that he saw the flare before realizing the flash was only lightning. Shortly thereafter, Woomera reported flare ignition; the pilot still saw lightning—but only as a big blob of light, never like the jagged streaks seen nearer Earth. Again, as on past missions, the flare launching area was cloaked by clouds. Minutes later, however, he reported seeing the outline of a city, which he guessed to be Brisbane, Australia.

With careful adjustments, Schirra peered into the periscope on his first night trip through space, endeavoring to prove its optical advantages. Very graphically, he finally reported, "I couldn't see schmatze through it. Schmatze translated means nothing." He, like Carpenter, found the periscope was excess baggage during the daytime and nearly useless at night. Reaching the morning side of Earth near Hawaii, he recoiled when the Sun, glaring through the scope, almost blinded him. Placing a chart over the scope, he commented that it "helps no end to cover up that blasted periscope."

Though he did not feel rushed in his few tasks, Schirra did notice a remarkable "speeding up of time" as distance flew by so rapidly. After crossing the Pacific, he reported to Scott Carpenter at Guaymas, Mexico, "I'm in chimp configuration," meaning that the capsule systems were all on automatic and working beautifully. Even the temperature range had now become more comfortable, and one more adjustment of the knob would end that problem. He then told Carpenter that he would soon start his first daytime yaw maneuver, using the window as a reference. Schirra said to Slayton, while sailing over the Cape, that the "reticle is working well for yaw, as well as for almost any other attitude." Any object that could be seen on Earth could be centered on the window reticle long enough to judge yaw misalignment. Always the most difficult of the three axes to judge precisely, as demonstrated during MA–7, yaw alignment with the flight path was a major control task to be tested by the MA–8 mission. Over areas of extreme cloudiness, there was no worry so long as rifts or thunderheads provided breaks in the blanket of cloud cover. By the end of his first circuit, Schirra felt he had become so adept in determining yaw attitude that he could

estimate any yaw angle his ship happened to take away from the flight path.

The pilot for a second time carefully compared his visual ability, both with and without the periscope, to position the capsule's attitude correctly. He felt satisfied with the results. He conceded that by using the periscope on high magnification he could obtain the yaw attitude faster than with the window, but speed was unnecessary in most cases.

Schirra had to devote much of his time during the first orbit and a good portion of the second to correcting his suit temperature settings. Perspiration salted around his mouth as a result of suit inlet temperature reaching 82 degrees F; he became quite thirsty, but he resisted opening the visor so the suit could have every opportunity to settle in a more comfortable range. Despite the heat—which he described as comparable to what he had endured mowing his lawn in Texas on a summer's day—all other aspects of the flight were going well. *Sigma 7* had consumed 1.4 pounds of fuel on the first orbit, Schirra noted as he reported the status of the spacecraft systems. He saw the exterior particles first reported by Glenn and tapped the cabin wall to obtain the same shower effect Carpenter reported. Much of his conversation with the tracking sites involved the status of his suit circuit. He seemed to enjoy talking with the communicators during his first orbit, but later he would complain that this became a chore, especially when he was trying to concentrate on his work.

On Earth's nightside, Schirra reported that the Moon made an excellent yaw reference; after completing and reporting on the yaw maneuver, Schirra told Slayton in the Mercury Control Center that he had shifted back to the automatic system. By now the temperature had subsided enough to permit a quick drink of water. He took the opportunity during this respite to report that all systems were performing very well. So far he had felt only one unwanted spurt from a 24-pound thruster when he returned to fly-by-wire for a yaw-maneuver exercise. Becoming a little bored with automatic flight halfway around the world, Schirra shifted to the manual-proportional system and produced a similar moment of double authority. About two percent of the manual supply spat out in a pitch-down motion of the spacecraft. "It was my boo-boo," he confessed.

Over Muchea, Australia, on his second pass, Schirra began a more serious and considerably more difficult night-yaw experiment. He was to test his ability to use celestial navigation to align the spacecraft properly. Using star-finder charts, Schirra was supposed to orient himself by positioning *Sigma 7* in relation to known stars or planets and the Moon. Then he was to test his sense of facing to the right or left of his flight path by watching the apparent motions of heavenly bodies. The pilot found that the airglow layer was an excellent reference for pitch and roll. This belt, which appeared very thick above the horizon, could provide reference for these attitudes quite accurately. For experimentation with the airglow layer, he positioned *Sigma 7* so that it appeared to aim at the upper layer of the belt. The panel indicators then showed a zero reference in pitch.

Schirra conceded that night-yaw reference could be a bit of a problem. The field of view from the window did not make it easy to identify the constellations and find a known star. Preferring to obtain the correct yaw reference on the daylight side, Schirra seemed to lack confidence in his ability to effect the night maneuver. To some degree his difficulty stemmed from his star-finder charts, which had been fixed in their relationship to Earth for a period up to about 7:16 a.m. on October 3. Schirra, now deep into the second orbit, knew that his launch time had been 7:15. The difference in time, plus his restricted field of view, reduced the value of this night-yaw exercise; but as it turned out, telemetry data received at the Muchea tracking station showed his error to be only four degrees.

During the night-yaw maneuver, Schirra happened to notice one excellent celestial pattern that he could use to align the spacecraft in the retrofire position when it was time to reenter the atmosphere. Checking the panel indicators against his own observations, he determined that the correct retrofire attitude would place the planet Jupiter in the upper right-hand corner of the window, the double-star constellation Grus tracking in from the left side of the window, and the star Fomalhaut at the top of the window, near the center.

Across the Pacific, Schirra again placed the controls in the automatic, or "chimp configuration," mode. He chatted with Grissom at the Hawaiian site about how well the spacecraft's systems were working. Grissom had made some rather strong points concerning the manual-proportional control operation during his suborbital flight, and the two astronauts, in a space-to-Earth conversation, compared notes. Just as Hawaii lost his signal and California picked it up, Schirra called that the "fireflies" were coming into view. "I have a delightful report for one John Glenn," he told the California communicator. "I do see fireflies." Impressed by the view out of the window, even though much of the California coast was covered with clouds, Schirra remarked to Glenn, "It's kind of hard to describe all this, isn't it, John?" Suddenly, through rifts in the clouds, he could see San Clemente Island, off the coastline. Then, looking northeastward, he saw more of the coastal area come into view, followed by the Salton Sea, an excellent view of lower California, the ridges of Mount Whitney, and several roads in the Mojave Desert area.

Although Schirra flew higher than either Glenn or Carpenter, he was rather unimpressed by the height of his voyage. Psychologically he had prepared himself for space flight, knowing that he would be flying 10 times higher than he had ever flown before. But once in space, the number, size, and detail of the objects he could see with the unaided eye, such as roads and terrain changes, made him actually feel no higher than he had climbed in an aircraft. "Same old deal, nothing new," he remarked in debriefing, "might as well be in an airplane at 40- to 50-thousand feet altitude."

According to his flight plan, if the yaw-reference checks had been satisfactory *Sigma 7* would be phased into drifting flight during the third orbit. After giving

Slayton a systems status report, Schirra proceeded to cage the spacecraft's gyros, cut off its electrical power, and allow *Sigma 7* to drift through space. Schirra took this opportunity to make an old psychomotor experiment that Robert B. Voas a year earlier had asked to be performed. Choosing three dials on the control panel, he closed his eyes and attempted to touch the target points. In a total of nine trials, he made only three errors, the largest being a displacement of some two inches. The weightless state, he concluded, created no disorientation or new problems in blindly reaching for his controls.

After that test, Schirra drifted along, reporting his status again to the Canary station and enjoying a brief period of looking out the window. He mentioned that his outer pane was streaked with a pinkish-orange film and surmised that this had emanated from the exhaust gases of the launch escape rocket. According to his flight plan, he was supposed to eat and drink now; although he said, "I'm having a ball up here drifting," eat and drink he did—peaches and ground beef mush from squeeze tubes.

Out over the Indian Ocean, he informed the tracking ship in that vicinity that he had switched the electrical power back on and gone into fly-by-wire control to check systems operations after the "powered down," or free-flight, period. Excitedly, the Indian Ocean ship communicator told Schirra that some of the crew topside had actually caught sight of *Sigma 7* for five minutes and through nine degrees of tracking. Schirra, quite pleased, said, "I'll have to go by and say hello." The pilot then reported that powering up again presented no difficulty; all systems worked beautifully, with absolutely no responses from the high thrusters. Smoothly transferring into the automatic stabilization and control system, he began to look toward the heavens for familiar stars. When the Moon failed to show, he went to the fly-by-wire, low-thruster control to bring it into sight. He identified Cassiopeia during the process, then said, "There's our friend the Moon." Over Muchea again by this time, he told the communicator that he had locked the automatic system onto the disk of the Moon. Mercury Control had alerted the ground stations to pay particular attention to fuel usage by the thrusters. Canton Island and Kauai, Hawaii, rolled by underneath with everything working so well that Grissom, at the Hawaiian station, gave Schirra the official good news that he had a "go" for the full six orbits.

As *Sigma 7* came near the California tracking site on its third pass, Schirra told Glenn, "I'm going to shove off for a relaxation period," meaning he would cut his electrical power, cage his gyros, and start drifting again. Schirra's flight schedule now called for experimental observations and photography. He had to struggle getting the camera out of the ditty bag, but once out it was weightless, and Schirra easily snapped pictures from Baja California to Cuba as *Sigma 7* drifted along beautifully. Nearing the Cape, Slayton asked for a radiation reading from the hand-held dosimeter. Schirra replied that the value was so small that it was nearly unreadable. Then Kraft himself came on the air to compliment Schirra, to urge him to look for the giant Echo balloon-shaped satellite on his next pass over

Zanzibar, and to notify him that his voice would be broadcast live for two minutes during his next flight across North America. The enthusiastic pilot then exclaimed that he had just drifted into an inverted position (head to Earth) and "for some reason or another, you can tell that the bowl [spacecraft] is upside down." He saw the whole eastern coastline of the United States, took a picture of that, and then another of an interesting cloud formation. Still complaining that the camera was difficult to extract, he decided not to stow it in the case for a while. As for Echo, he never saw that (or any other) man-made satellite while in orbit.

Floating through space around the world on his fourth orbit, Schirra took pictures that struck his fancy, watched the nightfall, recognized several stars as they appeared, and looked at lightning in the thunderstorms covering portions of the Australian continent. As he came over the Pacific command ship, he facetiously reported to Shepard that his hydrogen peroxide had not evaporated and suggested that they should make some plans, the next time around, about retrofire countdown. Schirra then tuned on the radar ships *Huntsville* and *Watertown* for a communications check. As Hawaii was sliding by, he told Grissom that he was in inverted flight and that the impression was similar to "looking out a railroad train window. You see the terrain going by you." The yaw attitude of the spacecraft was clearly discernible against this background.

As he approached, head down and looking toward California on his fourth pass, Schirra joked with Glenn about his "real weird attitude" and transmitted another short status report. Then at 6 hours, 8 minutes, and 4 seconds elapsed time from launch, Schirra and Glenn began a dialogue heard by much of the western world via radio and television:

GLENN: Okay, Sigma 7. This is Cal Cap Com. You're at 6:08. Two minutes on live TV. Go ahead, Wally.

SCHIRRA: Roger, John. Just came out of a powered-down configuration where we had the ASCS inverter off. It came up in good shape and will stay on now for the rest of the flight. The amps and volts are reading properly. . . . I'm coming toward you inverted this time, which is an unusual way for any of us to approach California, I'll admit.

GLENN: Roger, Wally. You got anything to say to everyone watching you across the country on this thing? We're going out live on this.

SCHIRRA: That sounds like great sport. I can see why you and Scott like it. I'm having a trick now. I'm looking at the United States and starting to pitch up slightly with this drifting rate. And I see the moon, which I'm sure no one in the United States can see as well as I right now.

GLENN: I think you're probably right.

SCHIRRA: Ha-ha, I suppose an old song, "Drifting and Dreaming," would be apropos at this point, but at this point I don't have a chance to dream. I'm enjoying it too much.

GLENN: Things are looking real good from here, Wally.

SCHIRRA: Thank you, John. I guess that what I'm doing right now is sort of a couple of Immelmanns across the United States.

And here ended Schirra's epistle from space. Glenn continued the conversation in relative privacy, asking whether Schirra had noticed anything surprising about the haze layer. Schirra replied with another understatement—"It's quite fascinating"—but later he recalled that this phenomenon had been his biggest spatial surprise. Both Glenn and Carpenter had briefed him on the night view of the horizon from the heavens, but "it just never did sink in to me that it was as large in magnitude as it really was." Schirra remarked that the airglow layer covered about a quarter of his view out the window. When first sighted, he said, "I thought it was clouds, until stars appeared below." [29]

Halfway through the fourth orbit, liquid collected over the inner surface of his helmet faceplate, evidently from the water coolant circuit. Although Schirra was annoyed by this problem for the next two hours, he was thankful that the suit temperature remained reasonably comfortable. So long as his visor was sealed, he had to crane his head about inside the helmet to find a clear view out of the faceplate. He was still reluctant to disturb his suit temperature by opening his visor to wipe it clean.

Going into his fifth orbit, Schirra told Slayton by radio relay that the flight had been his first opportunity to relax since the previous December. His life had suddenly become so sedentary that he gladly used the bungee cord exerciser to tone up his muscles a bit. "Not exactly walking around," he said, "but a little bit of stretching." Because *Sigma 7* was now over the Yucatan Peninsula, communications with the Cape were a little strained, causing Slayton to quiz Schirra, "Did you say you'd like to get up and walk around?" The ground controllers cleared the matter by switching circuits to a relay communications aircraft.

Schirra now began another check of the manual-proportional attitude controls, recording a third brief instance of double authority control. Regarding this latest spew of fuel, he complained that he "really flotched it. It's much too easy to get into double authority, even with the tremendous logic you have working on all these systems." His check of all the axes of movement proved that the manual-proportional system was still in good working order. After this trial he returned to observing and photographing targets of opportunity.

As he prepared to look for the 140-million candlepower light near Durban, South Africa, Schirra reported "getting some lighted areas over the southern tip of Africa. . . . I definitely have a city in sight." Betting that this was Port Elizabeth, a city a little more than 300 miles to the southwest of Durban, Schirra did not seem surprised that Durban was being drenched with rain and its brilliant light was not visible on this pass.

Passing into its fifth revolution of Earth, *Sigma 7* still performed beautifully in all respects. Astronaut Schirra had little to tell the ground tracking station except to repeat how well the systems were working and how gorgeous were the sights. With each orbit, he was now moving farther from the beaten track nominal to a three-pass flight, and the periods of silence were longer. A lighted area appearing much like an airport showed up in what he surmised were the

Philippine Islands. "Possibly it's at Zamboanga," he guessed, a city on the southwest coast of Mindanao. Minutes later he talked with Alan B. Shepard aboard the Pacific command ship, reporting with pleasure that his fuel supply stood at 81 and 80 percent in the automatic and manual tanks, respectively. His oxygen supply was properly pressurized, and his suit temperature was at a comfortable 62 degrees. Shepard replied, "Well, I could say that you were definitely go." Quickly he checked in with the *Huntsville* and *Watertown,* presenting, as he put it, a "hunky dory" report. As the pilot came over the Kauai station, Grissom fed him the correct retrosequence time that he should use on his next, and final, pass. Checks with Glenn at Point Arguello and with Carpenter at Guaymas showed that communications should be good for checkoff and reentry during the sixth orbit. Schirra then bade farewell to South America with a "Buenos dias, you-all," to the Quito, Ecuador, communications relay station.

Going into the sixth orbit, Schirra almost regretfully began his preparations to return to Earth. On his last pass over South America, heavy cloud coverage obscured most of the hemisphere but he did catch sight of a large winding river. He reached for the slow-scan camera and pointed it downward at the surface of the window to capture the view, making a panoramic shot of the continent that he thought would aid the Weather Bureau in continental cloud analyses. Then he stowed the camera, rearranged the contents of the ditty bag and glove compartment, and began going down the checklist of actions to be accomplished before retrofire and reentry.

He shifted the control mode from the automatic system to the fly-by-wire, low-thrusters, and found his command of the system still worked well. He looked briefly out the window for the lights of Durban, but clouds still hid the glow of that huge lamp from sight. He closed the faceplate, found it fogging again, and opened it briefly to wipe the visor clean. The instrument panel showed that the inverter temperatures were in a good range, that the battery voltage checked out high, and that the oxygen pressure was holding its mark. Although quite comfortable, he decided to advance the suit-circuit knob "just a tad to increase the cooling for reentry," to Position 8. The checkoff proceeded so methodically that he had time to try another eyes-closed orientation test. He reached for the manual handle and felt it in his grasp. Then he reached for the emergency handle but brushed an adjacent radio box before touching it.

Down below, the Indian Ocean ship communicator asked if he needed any help in completing the pre-retrosequence checklist. "Negative," he replied. All was in readiness for the last-minute arming of the retrorocket squibs. He waited and watched until he came in range of Shepard aboard the Pacific command ship. In the darkness, he viewed a moonset, saw the proper star and planet pattern for his correctly aligned attitude swing into view, and noticed that one of his fingertip lights had burned out. Musing out loud for whoever could listen, he likened his situation once again to riding a train on celestial tracks leading back toward Earth. Listening to the humming of the systems, he was reminded also of a ship underway

at sea. As a pilot, Schirra curiously refused to compare his limited control of the spacecraft with his freedom of maneuver in aircraft.

When he came into range of the Pacific command ship, he glanced at the fuel levels: 78 percent in both the automatic and manual tanks, the meters read. Shepard asked him how he stood on the checklist. Completed, with the exception of arming the rocket squibs, Schirra replied. He told Shepard that his ship was holding well in the retroattitude mode on the automatic system, that the high thrusters were in good working order, and that he had the manual-proportional system in a standby position. With everything set, Shepard gave the countdown to arm the squibs on the "Mark!" Next came the retrosequence countdown. Eight hours and 52 minutes after *Sigma 7* lifted off from the Cape, the first retrorocket fired. When Schirra punched the button for this action, the tiny instant of time before the firing "seemed agonizingly long." As each retrorocket fired crisply at five-second intervals, Schirra was pleasantly amazed that the spacecraft appeared to hold as steady as a rock. Quickly he checked this impression with a glance out of the window; the star pattern he could see did not even appear to quiver. After retrofire he checked the automatic fuel gauge and found the needle hovering between 52 and 53 percent.

Then Schirra shifted gears to his favorite fly-by-wire, low-thruster mode of control. He armed the retropack jettison switch and the spent unit spun away. Shortly after retrofire his attitude control felt "a little bit sloppy," and he felt himself wobble toward reentry. Although this could have been corrected by using the low thrusters, he intentionally cut in the high thrusters to get into position quickly. Schirra pitched *Sigma 7* up to the 14-degree reentry attitude with no difficulty and cut in the automatic control mode to damp away undesirable motions. Then, as the engineers had asked him to do, he turned on the fuel-gulping rate stabilization control system (RSCS). His return to the atmosphere was "thrilling" to the astronaut. He said the sky and Earth's surface really began to brighten, but, most surprisingly, the "bear" he rode felt "as stable as an airplane."

Schirra realized that he had heard none of the hissing noises reported by Glenn and Carpenter. Possibly, he thought, his concentration on the rate control system caused him to miss the sounds. Having conserved his hydrogen peroxide so well thus far, Schirra was quite perturbed with the rate system because he could see the fuel supply being dumped like water being flushed. Resisting the temptation to switch to a more economical mode of control because the engineers wanted to evaluate this system once and for all, he pulled his eyes away from the gauge and looked out the window. He could see the green glow from air friction that Carpenter had reported. To him it looked limeade in color, almost chartreuse. Suddenly, as a three-foot strap flopped past the window, he exclaimed, "My gosh!" Then he remembered, "That's the same thing John saw."

Soon the barometric altimeter dial came into operation, and Schirra calmly waited for the needle to edge toward the 40,000-foot reading. He punched the drogue button, heard a "strong thrumming," and then felt the drogue parachute

pop open. What had felt like a smooth highway now seemed like turning off on "a bumpy road." As long as he could, the astronaut strained to watch "the drogue up there pounding away," but the window became virtually occluded by smoky deposits from reentry. Schirra then turned back and flipped on the fuel jettison switch.

At the 15,000-foot mark he ejected the main parachute and saw it stream and blossom at 10,500 feet. This event, as Schirra quipped, "sort of put the cap on the whole thing." As he started his descent to Earth, Schirra remarked to Shepard, "I think they're gonna put me on the number 3 elevator" of the carrier *Kearsarge*. *Sigma 7* missed this mark by a scant 4.5 miles downrange from the planned landing point, but the recovery force had the spacecraft well within its sights electronically and visually. The carrier made radar contact with *Sigma 7* at a slant-range of 202 miles; 90 miles uprange from the carrier, sailors of the destroyer *Renshaw* reported hearing a sonic boom. Men on the deck of the *Kearsarge* then saw a contrail, while a few of its crew claimed to see the drogue and others heard two successive sonic booms and saw the main chute unfurl. After nine hours and 13 minutes in flight, *Sigma 7* settled on the water, in full view of the ship's crew and the cameras of newsmen.

*Sigma 7* hit the surface with a "plop," as Schirra described it, and "went way down" before it surfaced and floated. He waited patiently for 45 seconds and then broke off the main parachute and switched on the recovery aids. Inside, the spacecraft remained dry and the temperature range was very comfortable as *Sigma 7* rode the lazy ocean swells. This condition prompted the pilot to exaggerate in debriefing that he "could stay in there forever, if necessary." Through the window he could see the green dye permeating the water in a widening perimeter, and he knew that the whip antenna had telescoped out fully. Seeing the antenna pole deploy while *Sigma 7* was still submerged, Schirra later joked that he thought he might spear another bluefish. All was well, and so far as this test pilot could judge, the Mercury spacecraft "had gone to the top of the list," even over the F8F aircraft he liked so well.

Long before Schirra's splashdown, the *Kearsarge* had launched helicopters with swimmer teams, and soon three swimmers jumped into the dye beside the floating capsule. During the 30 seconds while he was keeled over in the water, Schirra had had some trepidation about his watertight integrity. He momentarily wished for the pressure regulator handle that had been deleted from *Sigma 7* to save another pound of weight. As the capsule righted itself and remained shipshape, he noticed that communications had been better with Hawaii than they were with the *Kearsarge*. The pararescue men then cut the whip antenna and attached the flotation collar around the heatshield. Since he was comfortable, he radioed a request to the helicopter pilot that he "would prefer to stay in and have a small boat come alongside" and tow him to the carrier's cranes. Five men piled into a motor whaleboat and within minutes had covered the half-mile to the bobbing *Sigma 7* and attached a tow line to it.

Some nine hours and 54 minutes after launch, the small space ship was hoisted aboard the huge carrier. Five minutes later Schirra whacked the plunger to blow the explosive hatch, incurring the same kind of superficial hand injury as Glenn before him. He stepped out onto the deck of the *Kearsarge* and paused to acknowledge the jubilant shouts and applause of the ship's crew. As he walked down to the ship's sick bay, Schirra looked tired and hot but happy. When reporters called out, "How do you feel, Wally?" he replied, "Fine," with a flip of the hand.

For the next three days, the *Kearsarge* was to be his home during the medical examinations and technical debriefings. While still in his space suit and sitting on a cot in the officers' sickroom, he received successive congratulatory telephone calls from President Kennedy, his wife Josephine Schirra, and Vice President Johnson.[30]

Richard A. Pollard of MSC, Commander Max Trummer of the Navy, and several other physicians began to check Schirra in every medical way possible. When his phone calls were completed, about 45 minutes after he came on board, the systematic examinations began. At first appearance, the spaceman showed no evidence that he was dizzy or required walking assistance. He told the physicians, "I feel fine. It was a textbook flight. The flight went just the way I wanted it to." Contrary to the impression of some newsmen, the physicians did not find Schirra overly fatigued. He talked easily and actively assisted in his postflight physical. Only after he had been strapped on a tilt table did several unusual symptoms begin to appear. For example, when lying supine his heartbeat averaged 70 a minute; standing, it rose to 100. Blood pressure readings, although not so pronounced in range, registered differently in standing, sitting, and prone positions. His legs and feet assumed a dusky, reddish-purple color when Schirra stood up, connoting that his veins were engorged. This condition persisted for about six hours, and then the astronaut was permitted to retire for the night. The next morning Schirra's heart and blood pressure readings were near normal, and there was no evidence of pooling of blood in his legs when he stood.

Other than this minor anomaly, and the small lesion on his hand, Schirra seemed none the worse for his lengthy weightless sojourn in space. Life-systems specialists in NASA, at McDonnell, and at AiResearch, however, had another question: What caused the elevated suit temperatures during the first two orbits? Postflight inspectors dug into the matter promptly. The technical ills of the spacecraft's systems were more easily determined than the subtleties of man's physiological system; as it turned out, the flow in the suit coolant circuit had been impeded by the silicone lubricant on a needle valve's having dried out and flaked.

Postflight inspection of *Sigma 7* found little else that seemed out of the ordinary. Circular cracks on the ablation shield were moderately larger than on Glenn's and Carpenter's spacecraft; also it appeared that the shield had banged into the fiber-glass protective bulkhead upon impact, causing several small holes. Once again the heatshield showed some delamination from the center, but it still

**Flight of**
***Sigma 7***
**Oct. 3, 1962**



*Schirra, assisted by Cooper, heads for elevator that will carry them to the top of Gantry 14 where* Sigma 7 *awaits her astronaut.*





*Six orbits and a landing later, the whaleboat from the* Kearsarge *approaches* Sigma 7 *to help para-rescue men secure the capsule.*

Sigma 7 *is hauled aboard the principal recovery ship* Kearsarge.

appeared, as in past flights, that this occurred after reentry. Char depth on the shield, about a third of an inch, was quite nominal. The shield's center plug, which had been loose or missing after previous missions, stayed tightly in place. All in all, the inspectors found very few problems to analyze or to correct. The quality of the mission, of the hardware, of the software, of procedures, and of the pilot were all superb. In terminology the engineers agreed with Schirra that MA–8 was a "text book flight"—the best so far.

Walter Williams was especially jubilant over the MA–8 success; now he could confidently turn his operations team to the task of the day-long mission. Schirra's conservation of fuel and the excellent manner in which the spacecraft had performed, he said, made planning for MA–9, if not routine, at least considerably easier.[31]

Upon leaving the *Kearsarge*, Schirra received the leis of Hawaii and a tumultuous aloha. Then he flew back to Houston. In a press conference at Rice University, he reported about his spatial voyage to an American public that now was more conversant with the terminology of space technology. Thereafter, the hamlet of Oradell, New Jersey, greeted its most famous son, and from there Schirra went to Washington to receive the NASA Distinguished Service Medal from the President and, from the Chief of Naval Operations, the Navy's anchored version of the coveted astronaut's wings. Throughout the national hurrahs, however, the thoughts and words of participants in Project Mercury turned toward the advent of the day-long mission, another step toward reaching the lunar landing goal in the decade of the sixties.[32]

In mid-October 1962 the frightening Cuban missile crisis raised the spectre of nuclear holocaust. This dampened some of the postflight celebrations for Schirra. When President Kennedy appeared on nationwide television to explain his actions in blockading Cuba to force the Soviets to withdraw their ballistic missiles from Fidel Castro's island, Americans perhaps for the first time became acutely aware of the differences between medium-range (200–500-mile) "defensive" missiles and intermediate-range (1000–1500-mile) "offensive" rocket weapons. Neither the ICBM deterrent (defined as having an operational range of about 6000 miles) nor the success of Kennedy's confrontation of Khrushchev over Soviet IRBMs in Cuba could entirely relax the tension built up by this crisis. But it probably did more than any manned space flight had to educate the public on relative thrust capacities of rockets.

## Redevelopment for MA–9

The flight of *Sigma 7* had been so nearly idyllic that some observers, whether from cynicism or a kind of parental possessiveness, believed Project Mercury should be concluded on Schirra's positive note. Any further attempt at manned satellite flight with this first-generation hardware might press the program's luck too far and end sourly, if not calamitously. To cancel Mercury now would ensure the reputation of the project. Others argued it would sacrifice the living poten-

tial, as well as the intense desire, of the Mercury team to test man in space for one full day.[33]

Among Manned Spacecraft Center officials, there was no real decision to be made here; Mercury had begun in earnest in 1959 with a vision of an ultimate 18-orbit mission. But by October 1959, the inexorable growth in capsule weight and power requirements and the limitations of the network had forced the Space Task Group to erase that vision. The 18-orbit mission for Mercury had been revived by the summer of 1961, in conjunction with serious planning for Project Apollo and for a "Mark II" ballistic capsule design. And when Project Gemini was publicly named on January 3, 1962, as an interim program to fill the void before Apollo could be developed, Mercury engineers were already driving headlong toward the revived 18-orbit, 27-hour mission.[34]

During the period from September 1961 to January 1962, the word "capsule" had been erased from Mercury vocabulary in favor of the word "spacecraft." It was then that the Space Task Group (STG) became Manned Spacecraft Center (MSC), and NASA Headquarters reorganized Abe Silverstein's Office of Space Flight Programs into an Office of Manned Space Flight under a new director, D. Brainerd Holmes. In the midst of all this confusion, one thing had been clear: a Mercury spacecraft would have to fill the gaps in space, time, and knowledge before a Project Gemini two-man capsule could be developed and qualified. Although the physiological effects of extended exposure to weightlessness were still of primary interest, the only local policy issue was whether to adopt another change in nomenclature. Should the day-long sustained space flight be called MA–9 or Manned One-Day Mission (MODM)?[35]

Throughout the spring and summer of 1962, Mercury engineers, both at NASA centers and in St. Louis, had studied various design proposals for advanced versions of the ballistic spacecraft. The first Gemini capsule mockup review had been held at the factory on March 29, about the same time that Lewis R. Fisher, James E. Bost, William M. Bland, Jr., Robert T. Everline, and others had completed the specifications for a Mercury spacecraft for the manned one-day flight. Not until September, however, were negotiations settled with McDonnell over configuration changes to the four capsules set aside for this purpose (Nos. 12, 15, 17, and 20). A week before the Schirra flight, NASA Headquarters announced a new plan to phase Mercury into Gemini more quickly, if MA–8 and MA–9 met all expectations.[36]

After Schirra, Atlas 113–D, and *Sigma 7* excelled those expectations in nearly every respect, the Manned Spacecraft Center forwarded its sixteenth quarterly status report to NASA Headquarters, claiming:

> This report will be the final in the series of Project MERCURY, as such, since the MA–8 flight was the last mission of Project MERCURY. Future reports, although they will continue with the following number (17), will be on the status of the Manned One-Day Mission (MODM) Project (MERCURY Spacecraft).



*Following his MA–8 flight Schirra participated in the first shipboard technical debriefing of the Mercury program. Present were, left to right, Walter C. Williams, Glenn, Helmut A. Kuehnel, Robert Mercer, and Schirra.*




*Schirra at his postflight news conference, with Robert R. Gilruth at left and James E. Webb at right.*



*Schirra discusses his six-orbit space flight with Paul E. Purser (left), Wernher von Braun, and Robert R. Gilruth.*



*A technical review meeting at Space Systems Division in November 1962: left to right, Shepard, Christopher C. Kraft, Jr., Kenneth S. Kleinknecht, Walter C. Williams, Col. Robert Hoffman, Lt. Col. Toby Gandy, Bernhard A. Hohmann, and Cooper.*

Robert Gilruth's team, now located in temporary quarters at 13 buildings scattered over southeast Houston, was planning on an April 1963 launch date for MA–9, using spacecraft No. 20. On November 9, 1962, MSC's senior staff decided to aim for 22 rather than 18 orbits (or 34 rather than 27 hours), if all went normally.[37]

Walter Williams, Christopher Kraft, and Kenneth Kleinknecht proceeded to coordinate the mission planning with the Defense Department. This flight would involve vastly expanded support, because MA–9 was to criss-cross virtually all of Earth's surface between latitudes 33 degrees north and south of the equator. L. Gordon Cooper was officially announced as the pilot and Alan Shepard was named alternate in mid-November. McDonnell had estimated that this mission alone would cost $17,879,834 to complete, but as yet the Air Force, Navy, and Army participants had not conferred with NASA about new needs for the recovery network and medical support.[38] Clearly the MA–9 operation would not be able to challenge the 64-orbit feat of Nikolayev in *Vostok III* nor the 48 orbits of Popovich in the tandem *Vostok IV*, but MA–9 should go well beyond Titov's 17 orbits in *Vostok II*.

Meanwhile NASA and the Manned Spacecraft Center took their cues from President Kennedy and Administrator James E. Webb to mobilize greater effort toward the longer-range goals symbolized by Project Apollo. Only 55 persons staffed Kleinknecht's Mercury Project Office specifically to coordinate the diverse preparations for MA–9. Of the 2500 people employed by MSC in January 1963, only 500 were working directly on Mercury. The Gemini and Apollo teams were rapidly taking shape. NASA had just honored a group of nine old-time engineers from the Space Task Group as the "Mercury Spacecraft Inventors." The list of innovators was headed by Maxime A. Faget, and included Andre J. Meyer, Jr., William Bland, Alan B. Kehlet, Willard S. Blanchard, Robert G. Chilton, Jerome B. Hammack, Caldwell C. Johnson, and Jack C. Heberlig. But of that group of designers and developers, only Bland still remained employed in the Mercury Project Office. The rest had gone to work on Gemini and Apollo.[39]

One of the more significant New Year's resolutions enacted by NASA in 1963 was the appointment of a Manned Space Science Planning Group and of a Panel on Inflight Scientific Experiments, known informally as POISE, chaired respectively by Eugene M. Shoemaker and John A. O'Keefe. These two new groups were established to replace the Ad Hoc Committee on Scientific Tasks and Training for Man-in-Space and to ensure closer coordination between the Manned Spacecraft Center and the NASA Office of Space Sciences. They were only temporary expedients, staffed by most of the same people who had served earlier as consultants, but at least the manned space science programs for Gemini would be born more respectably than those for Mercury.[40]

At the first MSC senior staff meeting in 1963, Walter Williams warned his colleagues that two recent failures in Atlas-F launchings by the Air Force were inexplicable, or so far, at least, unexplained. Unless investigating committees

could clear up these failures soon, absolving the Atlas-D from any guilt by association, the MA–9 schedule might suffer. After five years of developmental experience, the Atlas ICBM had approached but still not attained a reliability high enough for comfort. The Atlas, even as modified and "gold-plated" by the "man-rating" tests and procedures, was still basically a ballistic missile, only converted and not designed to launch men into space. After five consecutive Mercury-Atlas launches without a failure, it was all too easy to forget this fact.[41] When the 130-D, Cooper's "bird," was first rolled out of the factory in San Diego on January 30, it failed to pass inspection and was returned for some rewiring.

Amid some charges from impatient newsmen that NASA had "muzzled" Cooper, the prime pilot took time out on February 8 to hold a press conference in Houston that refuted such public speculation. Cooper forthrightly admitted what little he knew about the booster problem and answered in picturesque detail a host of questions about new developments for his space suit, his spacecraft, his mission. "This is going to practically be a flying camera," he said, explaining the new slow-scan television monitor, the 70-millimeter Hasselblad and its different film packs, the special zodiacal-light 35-millimeter camera, and a 16-millimeter, all-purpose moving-picture camera. Cooper had difficulty convincing some reporters that the duration of the MA–9 mission would depend on how well it went—for "as many as 22 orbits"—and that he was still "struggling" to find a suitable name for spacecraft No. 20. But otherwise he talked freely about the most significant differences between the MA–8 and MA–9 spacecraft, although obviously he could not name all 183 of the changes then underway at McDonnell's Canaveral shop.[42]

Weight growth had been the primary nemesis in preparing for every Mercury mission, and this was especially true for the day-long mission. As is characteristic perhaps of all American technology, and especially of advanced modifications to military aircraft, overweight accessories tended to compromise the vehicles' performance. In the case of the MODM spacecraft, heavier batteries for more electrical power, another 4-pound bottle of oxygen, 9 pounds of cooling and 4.5 pounds of drinking water, plus 15 more pounds of peroxide fuel were imperative additions. Experimental gear, a full load of consumables for life support systems, and various modified components were also judged necessary, though heavier, installations. In an effort to compensate for these added weights, the 12-pound Rate Stabilization Control System (RSCS), a 3-pound UHF and a 2-pound telemetry transmitter, both of which were true redundancies now; and, in particular, the 76-pound periscope were deleted. Manned Spacecraft Center engineers almost discarded the fiber-glass couch in favor of a new hammock to shave away 17 more pounds, but that change did not materialize because the engineers feared the material might stretch and the astronaut bounce. So the MA–9 payload continued, through 31 weeks of grooming, to grow into an estimated weight of 3026.3 pounds in orbit.[43]

Such weight increases had become expected, at the rate of about two pounds per week of preparation, and early in 1962 the Mercury managers had called for

an extensive requalification program of the parachute and landing system. Known as Project Reef, these tests had effectively allayed all fears about the ring-sail parachutes' margin for error with heavier loads long before *Sigma 7* gave an even better demonstration. At the beginning of 1963, NASA scientists from other centers were pleased to gain some voting strength on the 20-man committee established nine months earlier to decide what in-flight scientific experiments should be conducted. But the majority voting strength of this panel still remained with MSC engineers, whose weight-consciousness and power-consciousness effectively stifled the transformation of MA–9 and spacecraft No. 20 into a more purely scientific orbital laboratory.[44]

Another ground test program behind the scenes, namely Project Orbit, which by the end of February 1963 had completed a 100-hour full-scale simulated mission in its thermo-cryogenic vacuum chamber, stirred up concern that the reaction control thrusters might get sluggish or freeze during long periods of inactivity in space. In all other respects, Project Orbit seemed to certify that the McDonnell spacecraft and all subcontracted systems were ready and reliable for a full day or more up there.[45]

Meanwhile, the tiger teams at work on Atlas 130–D were exceptionally pleased when, on March 15, 1963, the second factory rollout and flight-acceptance inspections on this booster were completed without a single minor discrepancy. Philip E. Culbertson, Gus Groissant, John P. Hopman, and David R. Archibald of General Dynamics/Astronautics flew across the country to deliver to their test conductor at the Cape, Calvin D. Fowler, what they believed to be their best bird yet. Bernhard A. Hohmann and helpers at Aerospace Corporation had defined an offset of the booster engines to counteract the threatening roll rate that Schirra had experienced at liftoff. And on April 22 spacecraft and rocket were mated.[46]

By the end of April, all plans and preparations had been well laid and revised in accord with the precedents and lessons of previous flights. The detailed flight plan, technical information summaries, calculated preflight trajectory data, public information directives, experiments guidebook, and documentation directives were all disseminated. The world was girdled by military and medical recovery personnel waiting for May 14 and the launch of Gordon Cooper. A total of 28 ships, 171 aircraft, and about 18,000 servicemen were assigned to support MA–9. These included 84 medical specialists, a reduction by half in the number of medical monitors and corpsmen since Glenn's flight. This was a token of the confidence the planners now had in Mercury and its men.[47]

But that confidence was not shared by everyone. While Cooper struggled to select the most appropriate name for his capsule, criticism of NASA and its implementation of national space goals swelled once again. Philip H. Abelson, editor of *Science,* the journal of the American Association for the Advancement of Science; Warren Weaver of the Alfred P. Sloan Foundation; and Senator J. William Fulbright from Arkansas raised voices in protest against the Moon race and against manned space flight in general. The costs of manned orbital flight,

the confusion regarding "science" and "technology," and urgent social and political problems deserving equal attention were to be widely debated.[48]

Against this context, when Cooper finally announced his choice of a call-sign—*Faith 7,* symbolizing "my trust in God, my country, and my teammates"—NASA public affairs officers were described by the *Washington Post* as worried:

> The naming of the bell-shaped capsule—a tradition accorded to the astronaut riding it—has given Cooper some bad moments. He has picked *"Faith 7,"* which has drawn some raised eyebrows in the "image" conscious space agency.
>
> "Suppose that, for some reason, we lost the capsule at sea," said one source. "Then it would come out reading something like, 'The United States today lost Faith. . . .'" [49]

So much had happened, so many things had changed in the four years since Project Mercury had become publicized by the selection of its seven astronauts, that the Manned One-Day Mission seemed an appropriate new name to symbolize the differences. Now there was a second class of nine more astronauts-in-training; there was the national goal of a lunar landing before 1970; there were new facilities, new administrators, and thoroughly reorganized procedures and policies to follow. *Mariner II,* in its magnificent survey of Venus in December 1962, was interpreted a few months later as having proved Venus to be one destination in planetary space that might as well be forgotten as a target for manned landings. Mars remained a mystery, and so also did Earth's Moon, for that matter, but the decision to try Project Apollo made Mercury already merely a demigod. While Project Ozma used radio telescopes in a search for evidence of intelligent life elsewhere in the universe, *Telstar II* was launched May 7, 1963, to renew the hope that Earthmen might exercise greater intelligence than they had in the past by establishing more intelligent communications with each other.[50]

In the midst of the heat of scientific and political criticism of both Department of Defense and NASA space priorities and costs, NASA and the Mercury managers had to decide what, if anything, should be the next mission after MA–9. If Walter Williams and others at MSC had their way, an MA–10 mission, planned for a three-day sojourn in space, would follow. But they were overruled, and Julian Scheer, the new NASA Deputy Assistant Administrator for Public Affairs, announced emphatically on May 11, "It is absolutely beyond question that if this shot is successful there will be no MA–10." [51]

So Astronaut Cooper knew, as he made the final preparations after four years of training, that his flight would mark the end of the beginning. A well-known life insurance company subscribed to Cooper's faith by underwriting the first commercial astronaut policies, including one for Cooper. The Mercury operations team gathered at the Cape the second week in May and found *Faith 7,* Atlas 130–D, and Cooper all ready to take off. Only the weatherman, Ernest A. Amman, voiced his doubts about the May 14 launch date.[52]

At 6:36 on the morning of May 14, Gordon Cooper was sealed inside his *Faith 7* spacecraft atop the steeple that was his Atlas. He checked off all his sys-



*The worldwide interest and sense of identification with Project Mercury was always apparent. From Glenn's flight on, one country that particularly responded to the challenges of manned space flight was Australia. Shown here on April 21, 1963, is Premier of Western Australia David Brand (center) presenting the original painting, "Perth, the City of Lights," to Manned Spacecraft Center. Astronauts Schirra and Slayton accepted this commemoration of Perth's role in Project Mercury.*

tems and awaited completion of the blockhouse and Control Center checkoffs, which should count down to ignition about 9 o'clock and lift him up to insertion about 9:05. A suction-cup force pump, the kind commonly called a "plumber's friend," had been Alan Shepard's parting gift to Cooper, but the instruction inscribed on the handle, "Remove before launch," had been obeyed. It would not make the long trip with Cooper.

While waiting, Cooper heard the secondary control center on Bermuda report that its basic C-band radar system was misbehaving both in azimuth and range. So he napped for a time during repairs. When Bermuda had corrected the difficulty, at about 8 o'clock, the countdown was resumed, and the gantry was ordered back. But the diesel engine failed to move the gantry, and engineers scurried around, looking for the proper plumber's helper to repair a fouled fuel injection

pump. More than two exasperating hours were lost on the "fail-safe" diesel locomotive before the count could resume.

At high noon, the gantry was driven back. But radar data from Bermuda, which was vital to the go/no go decision before the point of no return, now was intermittent. The launch was postponed. Cooper emerged from his capsule, saying, "I was just getting to the real fun part. . . . It was a very real simulation." Later that afternoon he went fishing, while checkout crews stayed at the pad, seeking out unsuspected trouble spots such as the diesel fuel pump.[53]

That night Mercury Operations Director Williams broadcast the word: "All systems are go, and the weather is good. Let's pick up the count and go." Cooper lay down to sleep, confident that his safety and the mission would keep until he should awake and take his place.

Next morning the countdown proceeded smoothly. Cooper had lain in the capsule only two and a half hours when he heard the final chant:

"T minus 10, 9, 8, 7, 6, 5, 4, 3, 2, 1. Ignition. Liftoff." [54]

## *Faith 7* for 22 Orbits

Thirteen seconds past 8:04, range-zero time, on the morning of May 15, 1963, Mercury-Atlas 9 lumbered upward the two inches that defined liftoff and thundered on toward its keyhole in the sky. Inside MA–9, Astronaut Gordon Cooper felt the smooth but definite push intensify as *Faith 7* gained altitude faster each second. His clocks marking the moments in synchronization, Cooper shouted through the din of the afterburner behind him to Walter Schirra, his predecessor and now capsule communicator at the Cape, "Feels good, buddy. . . . All systems go." [55]

Sixty seconds upward, MA–9 initiated its pitch program, and Cooper felt the max-q vibrations grow, but the rate gyros sensed greater lateral oscillations than the pilot did. Six or seven swings from peg to peg on his instruments, and the flight smoothed out. Two minutes and 14 seconds upward Cooper heard "a loud 'glung' and then a sharp, crisp 'thud' for staging" as booster engines cut themselves out and off. Then away flew the needless escape tower, and at three minutes after launch cabin pressure sealed and held while Cooper reported, "*Faith Seven* is all go."

The Atlas sustainer engine continued to accelerate, and its guidance system performed perfectly for two more minutes before SECO. *Faith 7* and "*Sigma 7*" swapped remarks on the sweetness of the trajectory. Schirra, at the point of Cooper's orbital insertion and capsule separation, said, "Smack dab in the middle of the go plot. Beautiful." And Cooper replied, after turning around on the fly-by-wire, "Boy, oh, boy . . . working just like advertised!"

In full horizontal flight over Bermuda at 17,547 miles per hour, Cooper watched his booster lag and tumble for about eight minutes, then checked his temperatures and contingency recovery areas, and tried to adjust to the strange

new sensations and perspectives at a little more than 100 miles (near his perigee) above sea level. Floating higher in his couch, now that he was weightless, Cooper agreed with Carpenter's report that an astronaut's sense of the cockpit changes when he reaches zero g and no longer feels himself lying flat on his back. Status checks with the Canary Islands and Kano, Nigeria, came on so fast that Cooper could hardly believe he had crossed the Atlantic Ocean and half of Africa already.

Over Zanzibar, he learned that his orbital parameters looked good enough for at least 20 revolutions and that all *Faith 7*'s telemetry was working well. His suit temperature fluctuated somewhat erratically, but as he watched his first sunset from space over the Indian Ocean he forgot his discomfort while looking at the airglow, spotting the twinkleless stars, and observing sheet lightning in scattered thunderstorms "down under." He saw the lights of Perth, Australia, on schedule 55 minutes after liftoff, and over Canton Island, in the Polynesian Archipelago, just south of the equator, the Sun began to rise behind him (as he flew backward toward the sunrise), and Cooper reported observing Glenn's "fireflies," or Carpenter's "frostflies," drifting along with the spacecraft at five miles per second.

From Guaymas, Mexico, Grissom, acting as capsule communicator, officially relayed the computer-blessed "go for seven orbits." Cooper, audibly impressed with the perfection of the flight so far, said, "It's great. . . . quite a full night. . . . everything appears very nominal on board here." As Cooper passed over the launch site at Cape Canaveral, Schirra raised him on the radio circuits once again and complained, "You son-of-a-gun, I haven't got anything to talk about. . . . I'm still higher and faster, but I have an idea you're going to go farther." The manned one-day mission was off to an auspicious start. Alan Shepard, who had been Cooper's backup pilot and was now also talking to *Faith 7* from Mercury Control, coached Cooper into his second orbit, saying, "All of our monitors down here are overjoyed. Everything looks beautiful."

Cooper thought so, too. All his spacecraft and physiological systems performed perfectly on his first two orbits. His only complaint concerned an oily film on his "windshield" that seemed to be on the outside pane of the window. Between Zanzibar and Muchea on his second pass, Cooper dozed off for a four-minute nap and then drifted across the Pacific, observing storms while inverted and stars when facing spaceward.

Beginning with his third orbit, the astronaut checked over the 11 experiments in which he was to participate. He prepared to eject a six-inch-diameter sphere, equipped with polar xenon strobe lights, that was to test his ability to spot and track a flashing beacon in a tangential orbit. At three hours and 25 minutes elapsed time, Cooper clicked the squib switch and heard and felt the beacon kick away. But, try as he might, he could not see the flashing light in the dusk or on the nightside during this round. On the fourth orbit, however, he did spot the beacon at sunset and later saw it pulsing. So he knew he had indeed launched a satellite from his satellite. Cooper jubilantly reported to Carpenter on Kauai, "I was with the little rascal all night."

Subsequently, on his fifth and sixth orbits, Cooper saw the flashing xenon several more times, and likewise spotted the constant xenon ground light of 44,000 watts placed at Bloemfontein, a little horseshoe-shaped town in the Union of South Africa. Having eaten some bite-sized brownie and fruitcake foods and excreted periodic samples for urinalysis, Cooper also kept up with his calibrated exercises, took oral temperatures and blood pressure readings, and did other duties required for the highest priority experiments of the MA–9 mission, the aeromedical ones.

Also on his sixth orbit, after nine hours in space, the astronaut set his cameras, attitude, and switches to deploy a tethered balloon, similar to the one tried on MA–7, for aerodynamic studies of drag and for more visual experiments. The balloon, a 30-inch-diameter Mylar sphere painted fluorescent orange, was to be inflated with nitrogen and attached by a 100-foot nylon line to the spacecraft antenna canister; a strain gauge in the canister should be able to measure the differences in pull on the balloon at apogee (166 miles) and perigee (100 miles). Cooper carefully went through his checklist, then tried to eject the balloon package, but nothing happened. He tried again, and still nothing happened. Because the antenna canister was later lost, no one ever knew why the tethered balloon failed to eject. But the second failure of this experiment was more severely disappointing than the first.

When Cooper surpassed Schirra's record by moving into a seventh orbital pass, he was engaged with the radiation experiments and with the hydraulic work of transferring urine samples and condensate water from tank to tank. During the automatically recorded radiation measurements, he had to turn the recorders on and off precisely on time and estimate accurately, without benefit of gyros, his drifting spacecraft's attitude. The hydraulic work was more difficult, because the hypodermic-type syringes used to pump the liquid manually from one bag container to another were unwieldy and exasperatingly leaky. At 9:27 elapsed time, Cooper spoke into his tape recorder, "The thing about this pumping under zero g is not good. [Liquid] tends to stand in the pipes, and you have to actually forcibly force it through."

After 10 hours of the mission, Zanzibar officially informed Cooper that he had a go for 17 orbital passes. The tracking, communication, and computing facilities at Goddard Space Flight Center in Maryland had long since settled down to a routine in following *Faith 7* around the world. The actual orbital parameters for Cooper's flight were proving so close to those planned that the differences were measurable only in tenths of a mile and hundredths of a degree. MA–9 was circumnavigating Earth once every 88 minutes and 45 seconds at an inclination angle of 32.55 degrees to the equator. Soon, as Earth turned beneath Cooper, his orbital track would have shifted too much to keep him within range of most of the scattered tracking and communications sites in Mercury's worldwide network. Then, too, the word "orbit" would become confused, because passing

over the same meridian on the rotating planet is not the same as passing through the space-fixed point of orbital insertion.

Cooper spent his last "orbit" before his scheduled rest period, on orbits 9 through 13, in extensive activity. He finished the radiation measurements; he ate his supper of powdered roast beef mush and gulped some water; he took pictures over India and Tibet; and he checked all his machinery for readiness to power down and drift and dream for the next seven hours or so. Passing from the Himalayas to Japan in less than five minutes, Cooper was aroused by John Glenn's second transmission from the tracking ship *Coastal Sentry,* located near Kyushu. Veteran spaceman Glenn assured Astronaut Cooper, "You're sure looking good. Everything couldn't be finer on this pass." Ten minutes later Cooper had traversed the Pacific lengthwise in a southeasterly direction and had come over the telemetry command ship *Rose Knot,* positioned near Pitcairn Island, at latitude 25 degrees south and 120 degrees west. There he gave a full report on all systems; the shipborne communicator advised him to "settle down for a long rest."

But Cooper was still too excited and fascinated to feel sleepy. Orbit 9 was to carry him again around South America, over Africa, northern India, and Tibet during daylight, and he resolved to record on film some of the remarkable things he could see while looking down at open terrain. On this circuit Cooper snapped most of his best photographs, demonstrating his contention that he could see roads, rivers, small villages, and even individual houses if the lighting and background conditions were right. High over the highest plateau on Earth, the Tibetan highlands, where the air is thin and visibility is seldom obscured by haze, Cooper thought he could even judge speed and direction of ground winds by the smoke from the house chimneys.

In their third radio contact, John Glenn, as "Coastal Sentry Quebec," advised Cooper, who had now been in space over 13 hours, 34 minutes, that he should "tell everyone to go away and leave you alone now." Cooper then relaxed and fell into a sound sleep. He awoke drowsily an hour later when his suit temperature got too high. Intermittently, for the next six hours, during orbital passes 10 through 13, Cooper napped, took more pictures, taped status reports occasionally, and cursed to himself over the bothersome body-heat exchanger that kept creeping away toward freezing or burning temperatures. At the end of his rest period, Cooper taped his surprise at having napped so soundly that neither floating arms nor weightless dreams had startled him into awareness of where he was when he woke. But he cautioned psychologists not to make too much of this:

> Have a note to be added in for head-shrinkers. Enjoy the full drifting flights most of all, where you have really the feeling of freedom, and you aren't worried about the systems fouling up. You have everything turned off, and just drifting along lazily. However, I haven't encountered any of this so-called split-off phenomena. Still note that I am thinking very much about returning to Earth at the proper time and safely.



*Cooper enters his spacecraft, assisted by suit technician Joe W. Schmitt.*

**Flight of *Faith 7***
**May 15–16, 1963**



*Liftoff.*



*Cooper photographs the rugged Tibetan lake country (above).*



*Mercury Control relaxes after* Faith 7; *left to right, Robert R. Gilruth, D. Brainerd Holmes, and Walter C. Williams.*

Coming around Muchea again, on his fourteenth pass, Cooper checked over all his systems, found his oxygen supply plentiful, and reported his peroxide fuel for attitude control showing 69 percent remaining in the automatic tank and 95 percent in the manual. He was in good shape, and all systems were still working "as advertised." At this point, Gordon Cooper spoke a prayer into his tape recorder aboard *Faith 7*, high in the heavens over the South Pacific. The MA–9 mission was well beyond its midpoint in time and space, and Cooper was humbly grateful that everything was still nominal. Physiologically his vision he knew was abnormally good. Philosophically the vision of this eighth man in history to orbit Earth in a manned satellite was bound to his culture, his times, and his origins in Oklahoma.[56]

Orbit 15 was consumed largely in calibration of equipment and synchronization of clocks, since by now Earthmen had experienced one more full 24-hour day of grace, whereas *Faith 7*'s elapsed time was faster by some 16 seconds than range-zero elapsed time. Orbit 16 brought Cooper back over Cape Canaveral and onward, virtually retracing his first shadow over Earth. The President of El Salvador had radioed greetings on pass 15, and on 16 Cooper sent a similar political greeting to African leaders meeting in Ethiopia. Then he buckled down immediately to another high-priority experiment requiring elaborate timing precautions.

As he entered Earth's shadow, or nightside, on this sixteenth orbit, Cooper caged and freed his gyros in such a manner as to allow his automatic attitude control system to torque the spacecraft slowly in pitch through the plane of the ecliptic. He could view, through his window, the mysterious phenomena of zodiacal light and night airglow layer. Together these two different objectives were called "dim light" phenomena, and the experimental photographs were designed to answer astrophysical questions about the origin, continuity, intensity, and reflectivity of visible electromagnetic spectra along the basic reference plane of the celestial sphere. They might also help answer some questions about solar energy conversion in the upper atmosphere. From Zanzibar, past the Canton Island station, Cooper called out the count as he clicked the series of astronomical photographs. Although the zodiacal light pictures turned out underexposed and the airglow shots overexposed, they were of usable quality and supplemented Carpenter's pictures from *Aurora 7* nicely.

Over Mexico, Cooper shifted to the next most important photographic task, that of snapping horizon-definition imprints in each quadrant around his local vertical position. Just as University of Minnesota scientists had prepared him for the zodiacal light task, so Massachusetts Institute of Technology researchers had arranged for these snapshots to aid in the design of a guidance and navigation system for Project Apollo. Cooper's horizon-definition pictures marked a significant advance beyond those from the MA–7 mission. In contact with the Cape once again, Cooper lightheartedly complained like a typical American tourist, "Man, all I do is take pictures, pictures, pictures!"

But he was not through yet. On orbits 17 and 18 he took infrared weather photographs of good quality and a few excellent moonset Earth-limb pictures. Meanwhile, he resumed the geiger counter measurements for radiation, continued his aeromedical duties, and adjusted his television monitor at the request of ground observers. The eighteenth pass over the United States, like the sixteenth, gave his extraordinary vistas of his country from southern California, across Dallas the first time and Houston the second, to the Florida peninsula. He sang during orbits 18 and 19, still surprised with every pass, still marveling at the greenery on Earth and on his instrument panel as he came toward his thirtieth hour in space.

Although "this fine plumbing they put in this thing" proved more troublesome later, Cooper had learned to adjust his suit temperatures for comfort and to eat and drink over the rim of his helmet fairly effectively, if awkwardly. Then on his nineteenth orbit, while checking his warning lights before a high-frequency antenna test over Hawaii, Cooper noticed the first potentially serious systems anomaly of his mission.

A small telelight lit up green, indicating that *Faith 7* was decelerating and that the centripetal force of gravity had overcome by .05 g the centrifugal force of the spacecraft's orbital moment of inertia. This had to be a false indication, reasoned Cooper, because he felt, and his loose gear still appeared, weightless. But were g forces building up imperceptibly? California confirmed no such indication. Mercury Control showed great concern over the implications of this little light for the attitude stabilization at retrofire. The fears of the flight controllers were realized on the next pass, when Cooper lost all attitude readings. Then, on the twenty-first orbit, a short-circuit occurred in a busbar serving the 250-volt main inverter, leaving the automatic stabilization and control system without electric power. The minor glitch had become a serious hitch.

Mercury Control Center was in a flurry of worried activity, cross-checking *Faith 7*'s problems and Cooper's diagnostic actions with identical equipment at the Cape and in St. Louis, then relaying to each communications site questions to ask and instructions to give. Cooper remained cool, if not calm, now that his alertness had been stimulated by a medically prescribed pill of dextroamphetamine.

On the twenty-first pass (over the tracking ship *Coastal Sentry*), John Glenn helped Cooper prepare a revised checklist for retrofire procedure during the next, and last, time around. Only Hawaii and Zanzibar were within voice radio range on this last circuit, but communications were good. When the ASCS inverter blew out, Cooper also noted that the carbon dioxide level was rising in both his suit and cabin. "Things are beginning to stack up a little" was his classic understatement to Carpenter, and then Zanzibar heard him say he would make a manual reentry.

Twenty-three minutes later Cooper came into contact with Glenn again, reporting himself in retroattitude, holding manually, and with checkoff list complete. Glenn gave the 10-second countdown, and Cooper, keeping his pitch down 34 degrees by his window reticle, shot his retrorockets manually on the "Mark!" Glenn reported: "Right on the old gazoo. . . . Dealer's choice on reentry here,

fly-by-wire or manual . . . It's been a real fine flight, Gordo. Real beautiful all the way. Have a cool reentry, will you."

"Roger, John. Thank you."

And that he did. All the complicated, crowded events of the next 15 minutes occurred precisely as planned, while *Faith 7* plummeted down through the atmosphere. Four miles ahead of the prime recovery ship, again the carrier *Kearsarge,* just south of Midway Island, the canopied capsule containing Gordon Cooper broke through a mild overcast and landed on the lazy waves of the blue Pacific.

Splashdown came 34 hours and 20 minutes after liftoff. Cooper professed disappointment that he too had "missed that third elevator" aboard "Begonia," meaning the *Kearsarge.* The spacecraft floundered in the water for a moment, then righted itself, as hovering helicopters dropped their swimmers and relayed Cooper's request as an Air Force officer for permission to be hoisted aboard the Navy's carrier. Permission was granted, and 40 hot, humid minutes later the explosive hatch blew open at the command of MSC engineer John B. Graham, Jr. Physicians examined Cooper for eight more minutes while he lay in the couch. Then they helped him emerge and steadied him during a moment of dizziness until he regained his equilibrium. Away in triumph marched the one-man crew of the one-day Mercury mission.[37]

Like Schirra, Cooper went through arduous medical, technical, and operational debriefings aboard the *Kearsarge* and later back at the Manned Spacecraft Center. He, too, was found to be dehydrated and suffering from a slight case of orthostatic hypotension. He had lost seven pounds since suiting up, but after drinking "a few gallons of liquid," he was fine, ebullient both mentally and physically, and convinced that "we certainly can elongate this mission." Robert C. Seamans, Jr., Associate Administrator of NASA, and Robert Gilruth, Director of MSC, had different ideas about MA–10, but Cooper reiterated the proof that "man is a pretty good backup system to all these automatic systems, and I think the mission was conducted just like it was planned . . . in spite of . . . equipment breaking down." [38]

In addition to undergoing technical debriefings over the next several days, Cooper was honored by parades through Honolulu, Cocoa Beach, Washington—where he addressed a joint session of Congress—and New York City, where he was hailed by one of the largest tickertaped crowds ever to greet an individual. Other crowds in Houston and in his hometown of Shawnee, Oklahoma, also celebrated the return of the sixth Mercury astronaut from space.

The fact that Cooper, like Glenn, had had to take action to save his mission from a probable failure added luster and meaning to the glory he received. While postflight inspections, data reduction, and mission analyses proceeded through the following month to pinpoint the causes of the few electromechanical faults of the flight, Mercury systems engineers could find no fault with pilot performance. Physicians, however, were cautious about the implications for longer space missions of Cooper's hemodynamic response.

## Faith 7
## Aftermath



*Members of the Project Mercury team were honored along with Cooper in ceremonies in the Rose Garden at the White House. Astronaut Cooper (left) and Christopher C. Kraft, Jr. (center), are shown with President Kennedy, Vice-President Johnson, and NASA Administrator Webb. In addition to Cooper, those receiving the NASA Distinguished Service Medal were G. Merritt Preston, chief of MSC's Cape Operations; Christopher C. Kraft, Jr., chief of the Flight Operations Division; Kenneth S. Kleinknecht, manager of Project Mercury; Floyd L. Thompson, Director of Langley Research Center; and Maj. Gen. Leighton I. Davis, Commander, Air Force Missile Test Center at Cape Canaveral. NASA Group Achievement Awards were made to Rear Admiral Harold G. Bowen, Jr., Commander of Destroyer-Flotilla 4, for the recovery forces, and to Maj. Gen. Ben I. Funk, Commander, Space Systems Division, for the Atlas program.*

*After speaking to a joint session of the Congress, Cooper left the Capitol: left to right, Mrs. Hattie Cooper, Vice-President Lyndon B. Johnson, Cooper and his wife Trudy, Speaker John McCormack, and Lady Bird Johnson.*





*Part of the 2900 tons of ticker tape and confetti that rained down on the official party as they rode along Broadway. Official estimate of this, the largest crowd in New York City history, was 4½ million.*

Probably no other result of the MA–9 mission excited more interest than Cooper's claim to have seen from orbit objects on the ground as small as trucks and houses. Skepticism on this point abated after the astronaut explained in detail to representative scientists at the Cape on May 21 just where, when, and how he could see dust and smoke below, from 100 miles directly above—if the contrast was right. Also at this, the first and only "scientific debriefing" following a Mercury flight, the value of extensive questioning of the subject pilot was clearly demonstrated, when Cooper was asked whether he could see Earthshine on the Moon. "Well," he replied, "the Moon was fuller as it was setting than it was on the nightside. It was almost a full Moon. Gee, that's funny, I hadn't even realized that before. It seemed to be almost full as it was setting, whereas on the nightside it was only a third of a Moon." [59] This Moonshine was clearly Earthshine. Other postflight analyses added praise for the sunshine that blessed *Faith 7*. "The sun literally smiled on MA–9," wrote J. C. Jackson and Niles R. Heller in Goddard's report of the network radio performance. "It [MA–9] was favored with better than average radio frequency propagation conditions for the present phase of the solar sunspot cycle." [60]

## Whither Gemini?

On June 6 and 7, 1963, Brainerd Holmes, Gilruth, Walter Williams, and Kleinknecht met with Administrator Webb, Hugh L. Dryden, and Seamans in Washington to make a final decision on whether to fly an MA–10 mission. President Kennedy had clearly left the decision up to NASA. Webb listened thoughtfully to the presentations of each NASA official, and although both he and President Kennedy had heard the Mercury astronauts' plea for one more Mercury mission, Administrator Webb announced before the Senate space committee on June 12, 1963, that "we will not have another Mercury flight." [61] It was to be 22 months before another American manned space flight.

Project Gemini, designed in 1961 to double the volume while retaining the basic shape and systems of the McDonnell-Mercury spacecraft, now was well into the development and redesign phase of construction. And the Martin Company's mighty Titan II rocket, in spite of a recent explosion on launch, had a record of nine cleancut successes out of 16 launches. Another Mercury-Atlas flight would have been a relatively economical way to extend space technology and fill the time (then estimated at a year) before Gemini-Titan could be flight-tested. But now that Project Apollo, employing a concept called lunar orbital rendezvous (LOR) to land a man on the Moon and recover him, was the ultimate goal of the decade, space rendezvous and docking had to be perfected. Mercury had served far more than its original purpose, but it could hardly be maneuverable. And so Project Gemini was designed to fill these gaps. As people were asking whither and whether Gemini was taking them, Mercury died a natural death, while Apollo and Saturn were aborning.

# Epilogue

PROJECT Mercury ended on the threshold of an era of exploration and discovery that staggers the imagination. Manned space flight of the most elementary sort had proved so successful that mankind seemed destined to embark on more ambitious celestial expeditions. The seventh decade of the 20th century also promised the logical extension of manned space flight technology beyond Earth's orbital corridor. Largely because of Project Mercury, which fostered Project Apollo and fathered Project Gemini, the United States had become committed to send men to explore the Moon only 350 years after Galileo first turned a telescope toward Earth's natural satellite.

Precedents set by Mercury were visible in many different ways to the taxpayers who watched the plans for NASA's Gemini and Apollo programs take shape. Most obvious was the configuration of the two-man spacecraft that McDonnell was building for launches by the Martin Company's Titan II missile. The Gemini spacecraft was to be a far more sophisticated vehicle, with modular components easily accessible, with a lift/drag ratio provided by an offset center of gravity, with a real, if limited, orbital maneuvering capability, and with ejection seats instead of an escape pylon. Except for its doubled size, its countersunk viewports, and its lack of the escape tower, however, Gemini looked much like the familiar Mercury capsule.[1]

Plans and boilerplate models of the Apollo spacecraft—rather, of the so-called "command module" that would house three men in a tubby pyramid during launch and return to Earth, via the Moon—were being tested by airdrops from airplanes, by a second Little Joe (II) booster series, and by pad aborts using a tractor-rocket escape pylon. These and other evidences of Mercury's influence on design, development, testing, and training for more advanced space flights showed that NASA's new Manned Spacecraft Center and its Marshall, Kennedy, and Goddard Space Flight Centers were managed and staffed by most of the same personnel who had formed the original Mercury team. Growth and thoroughgoing organizational changes affected many individuals adversely, but the core of the Mercury team moved forward in the mid-1960s toward further exploitation of "lessons learned" from Mercury for manned space flight at large.[2]

It was primarily to hasten concentration on the accelerated manned space program and to move away from the "egg-shell" Mercury package and toward

more nearly "first-class" spacecraft accommodations that James E. Webb, Hugh L. Dryden, and Robert C. Seamans had decided against a fifth manned Mercury-Atlas mission. NASA administrators wanted to concentrate their engineering talent as soon and as completely as possible on the next major step toward the Moon. They realized the political and psychological risks of a lengthy delay before Americans again went into space, but they took these in stride as necessary to the longer range goals.[3]

The week after Mercury was officially terminated, the Soviet Union launched into orbit *Vostok V*, carrying Valery F. Bykovsky, and two days later *Vostok VI*, with "cosmonette" Valentina V. Tereshkova aboard. Both flights ended on June 19, 1963, after 81 circuits by Bykovsky and 48 by Tereshkova. The flights followed slightly different orbital planes, exhibited no co-orbital maneuvers, and thus were similar to the tandem flights of Andrian Nikolayev and Pavel Popovich in August 1962. Tereshkova, trained as a parachutist and not as a pilot, became not only the first woman to go into space but also the first "layman," or non-pilot-engineer. When later she and Nikolayev were married and became parents, their healthy and normal baby seemed to indicate that fears about genetic damage from exposure to cosmic radiation were groundless.[4]

Most significantly, perhaps, *Vostoks V* and *VI* apparently signaled the end of the era of solo space flight. When the Soviets next sent men into space, on October 12, 1964, they began a new series with *Voskhod I*, which carried three men around Earth 16 times. And in 1965, the United States—taking what comfort it could, said one historian, from the fable of the tortoise and the hare—began its new Gemini series of twin-seated, maneuverable satellite missions, which were to make Mercury seem primitive indeed. When in March and June of that year Cosmonaut Alexei Leonov and Astronaut Edward H. White took their respective closely tethered "walks"—more nearly "swims"—in space, the fact that their command pilots were in the spacecraft to help in case of trouble seemed comforting.[5] Neither cosmonauts nor astronauts were ever again likely to go into space alone in their machines. In this sense only, therefore, man's heroic age of solo space exploration may be said to have ended in June 1963.

Almost four months after the passing of Mercury and the last Vostok flights, and only a few weeks before the national shock of President Kennedy's assassination, NASA and its Manned Spacecraft Center held their formal, public postmortem on the first American manned satellite program. Staged on October 3 and 4, 1963, at the Music Hall in Houston and attended by some 1300 people from NASA, the military, industry, and news media, this "Mercury Summary Conference" featured 20 papers on the overall program, with emphasis on Gordon Cooper's day-long MA–9 mission of May. Covering program management, booster performance, astronaut preparation, network operations, and MA–9 in-flight experiences and experiments, these papers constitute the best available technical overview of Project Mercury.[6]

The decorous proceedings were marred somewhat on the final day of the con-

ference by the appearance in newspapers throughout the country of a controversial story built around three pages of one report.[7] In a paper on "Spacecraft Preflight Preparation," four MSC engineers from Florida sketched the nature and evolution of the intricate and exhaustive checkout procedures followed at the Cape after McDonnell's delivery of one of its capsules to the launch site. Discussing "quality assurance," the authors dwelled on the problem of component defects and malfunctions discovered by Mercury inspectors in industrial hardware. Inspections for MA–9 turned up 720 system or component discrepancies, 536 of which were attributed to faulty workmanship. "In Project Mercury," concluded the MSC authors, "thousands of man-hours were expended in testing, calibration, assembly, and installation of a variety of hardware that later failed to meet performance specifications or that malfunctioned during systems tests in a simulated space environment." And often these delays could have been avoided "if adequate attention to detail during manufacture or thorough inspection before delivery had been exercised." [8]

Although the import of this rather didactic engineering treatise was that the history of Mercury spacecraft prelaunch preparations presented a good object lesson in the rigorous demands for quality control and reliability testing before manned space flight—as opposed to missile, instrumented spacecraft, or even aircraft experience—journalists blew the implied criticism of McDonnell into a *cause célèbre*. "NASA blasts industry" was the general tenor of the news dispatches coming out of Houston. Coupled with the General Accounting Office's contemporaneous criticism of NASA and its contractors in the lagging Centaur program, the news coverage of the summary conference added some ammunition for attacks on the "great moondoggle." [9]

In a hurriedly called press conference in Houston and in hearings the next week before the House Committee on Science and Astronautics, NASA, MSC, and McDonnell leaders denied that any resentment or dissatisfaction existed because of anything in past or present NASA-McDonnell relations.[10] Congress was satisfied, if the press was not, and this rather small tempest in a rather large teapot subsided quickly. The furor did suggest, however, that one of the lessons the Mercury technical staff had not learned well enough was extreme prudence in all public references to relations between NASA and its contractors and other agencies. Possibly the "candor at Canaveral" and elsewhere, for which the press had occasionally commended the Mercury team, would be the first casualty of the ongoing manned space effort.

In general, the authors of papers read at the Mercury Summary Conference, aware of the difficulty of making technological and administrative generalizations in the new and rapidly changing field of astronautics, offered only guarded conclusions about the significance of Mercury experiences for the Gemini and Apollo programs. But indirectly there, and more directly elsewhere, they did assess the state of the art and science of manned space flight, ask what Mercury had taught that might benefit Gemini and Apollo, and even venture some answers.[11]

Project Mercury lasted 55 months, from authorization through the one-day mission, and while the earliest planned orbital mission slipped 22 months past its first scheduled launch time, Mercury achieved its original objectives with John Glenn's MA–6 flight only 40 months after formal project approval. Compared with either advanced missile or aircraft development programs, this was a good record; but many engineers denied the validity of such a comparison.

Mercury mobilized a dozen prime contractors, some 75 major subcontractors, and about 7200 third-tier sub-subcontractors, and vendors, all of whom together employed at most about two million persons who at one time or another had a direct hand in the project. In addition, the NASA complement on Mercury eventually reached 650 workers in the Space Task Group and Manned Spacecraft Center and 710 elsewhere in research and development support of the project. A conservative estimate of the maximum number of military servicemen and Defense Department personnel supporting an individual Mercury mission (both MA–6 and MA–9) counted 18,000 people, and another conservative estimate added 1169 persons from educational and other civilian institutions. Thus, if the estimate of 1,817,000 workers employed by the Mercury vendors was too liberal and unrealistic, the total peak manpower figure of 2,020,528 was probably as accurate a figure as could be obtained.[12]

"Quick look" total cost estimates given at the summary conference in October 1963 showed that Mercury had cost $384,131,000 throughout the program, of which 37 percent went for the spacecraft, 33 percent for the tracking network, and 24 percent for launch vehicle procurement. Flight operations and "R and D" costs made up the remainder, as then estimated, but the final cost accounting was complicated by the unsettled conditions of closing and disposition costs and the mingling of Mercury and Gemini costs during 1962 and 1963. Through Glenn's flight, however, Mercury had cost about $300 million.[13] Through Cooper's flight NASA estimated the grand total cost of Mercury at slightly more than $400 million (see Appendix F).

NASA engineers and physicians listed three primary "lessons learned" from their experience with Mercury for manned space flight. Their foremost medical objectives had been fulfilled, and the responses of two men in suborbit and four men in orbit had shown that human beings can function normally in space if adequately protected. Rather than acceleration g loads and weightlessness limiting man's capacity to fly in space, the men who flew Mercury seemed to adapt to "zero g" surprisingly well. The main medical problems were simple personal hygiene in flight, and the postflight readjustment symptom of orthostatic hypotension. Both appeared to be curable by technical developments rather than by preventive medicine.

Secondly, Mercury had proven that final launch preparations took far more time than anyone had anticipated in 1958 to ensure perfect readiness and reliability of the machines and men. NASA had had designed, therefore, an automated digital system for the future, called "ACE," for Acceptance Checkout Equipment,

to reduce human error in environmental chamber testing and the length of time required on the flight line at the Florida spaceport. Thirdly, mission control requirements, integrating the astronaut with his flight monitors and directors around the world, had grown to encompass the fullest utilization of real-time telemetry, tracking, computing, and display data. Nothing less would suffice for future missions. Two more acronyms came into use, "MCC" for the new Mission Control Center at Houston, and "GOSS" for Ground Operational Support Systems, reflecting the degree of complex automation being installed for positive ground control of future space flights.

Studying how they could improve on their performance for succeeding programs, NASA officials and engineers listed several other valuable technological and managerial lessons from Mercury. In spacecraft design, problems had been encountered with safety margins, redundancy, accessibility, shelf-life of parts, interchangeability, and with materials whose behavior under unfamiliar environmental conditions had not been wholly predictable. Regarding qualification of systems and components, there should be more analysis in an effort to make techniques "conservative, complete, integrated, and functional." Fabrication and inspection standards carried over from development into manufacturing work should be made still more "rigorous, detailed, current, and enforced." Engineers working for the Manned Spacecraft Center, both in Houston and at the Cape, called for continuous upgrading of tests, inspections, and other validation procedures, particularly with respect to interface compatibilities between systems. In configuration control, NASA manned space flight developers recognized their perennial weight control problem and their need to become more responsive, more familiar in detail, and more aware of danger signals in the production and fabrication phases of their business. And the managers of Mercury now acknowledged that methods of management that had worked well enough in the first American manned space project would not suit Gemini and Apollo, already in motion. They had only begun to use the sophisticated Program Evaluation and Review Technique, called "PERT," which had evolved from the Navy's experience in its nuclear submarine and Polaris missile development programs. Now PERT and other management tools, such as the incentive contract, would have to be exploited to the fullest extent practicable.[14]

Perhaps the most significant lesson learned from Mercury was that man was still invaluable to the machine. Mercury saw the evolution of the astronaut from little more than a passenger in a fully automatic system to an integral and fully integrated element in the entire space flight organism. By the end of the project, the Mercury capsule, instead of simply being a machine with a man in it, had truly become a manned space vehicle. Mercury Flight Director Christopher C. Kraft, an engineer, spoke for all exponents of manned space flight, irrespective of discipline: "Man is the deciding element. . . . As long as Man is able to alter the decision of the machine, we will have a spacecraft that can perform under any known conditions, and that can probe into the unknown for new knowledge." [15]



*By November 1963, Project Mercury was clearly relegated to an honorable niche in history. The resources that had fed Project Mercury were now reorganized and recommitted toward Projects Gemini and Apollo. That reorientation is underscored in this photograph from President Kennedy's visit to Cape Canaveral on November 16. As the charts and models show, the subject is not Mercury but Apollo. The place is Blockhouse 34. The briefer is George E. Mueller, successor to D. Brainerd Holmes as head of NASA's manned space flight program. The front row, left to right: George Low, Kurt Debus, Robert C. Seamans, Jr., James E. Webb, President Kennedy, Hugh L. Dryden, Wernher von Braun, Gen. Leighton I. Davis, and Sen. George Smathers.*

Yet as Mercury faded farther into the past and Gemini and Apollo moved forward, some profound questions remained unanswered, and indeed usually not even asked.[16] In the democratic society of the United States, did the formal commitment to costly space exploration, and especially the increased emphasis on manned space flight beginning in the Kennedy administration, actually represent a consensus among the electorate? The pace and chances for success of this country's drive toward spacefaring preeminence depended, finally, on the continued willingness of the American taxpayer to pay the bills. However divergent may have been the appeals of the two political parties in the 1964 Presidential election, neither the Republicans nor Democrats seriously questioned the existence of such a consensus.

Many more mundane problems plagued the times, some seeming so overwhelming as to demand dramatic and drastic solutions like those widely presumed to issue from space technology. But the arrival of the so-called "space age," heralded by Mercury astronauts and Vostok cosmonauts, did capture most men's imagination and did seem to dwarf the petty quarrels of men and nations. Vague hopes for future peace and prosperity accompanied public support of preparations

for two- and three-man spacecraft, but fears about the population explosion, nuclear proliferation, and social disparities made many wonder whether the manned space flight enterprise was worth the effort and the price. Why send two or three men to the Moon when two or three billion others remained rooted in human turmoil? Questions similar to this found traditional answers in terms of national security, scientific curiosity, economic benefits, and technological by-products, but ultimately the national commitment was an act of faith.

Still, many Americans, both technically literate and illiterate, doubted the return from the $400 million spent on Project Mercury and the vastly greater expenditures being allocated for succeeding manned space projects. A substantial portion of the scientific community agreed with Alvin M. Weinberg, Director of the Atomic Energy Commission's Oak Ridge National Laboratory, who argued that "most Americans would prefer to belong to a society which first gave the world a cure for cancer than to the society which put the first astronaut on Mars." [17] Others deplored the fact that the American space effort was basically a "race to the Moon," having no nobler motivation than traditional nationalistic rivalry. Still others would confine the Nation's astronautical activities to unmanned instrumented space vehicles, thereby diminishing the cost of space exploration, as well as presumably avoiding the likely prospect that some day men would die in space.[18]

Nevertheless, whether most people in the United States approved or not, in the mid-1960s it seemed that not only American machines but selected and trained American citizens were in the space venture to stay. Project Mercury, leaving a legacy that perhaps was even more important psychologically than technologically, was already history. Hugh L. Dryden, only a few weeks before his death late in 1965, expressed his faith in manned space flight and offered a fitting epitaph for Project Mercury:

> Man is distinguished from other forms of life by his powers of reasoning and by his spiritual aspirations. Already the events of the last seven years have had profound impact on all human affairs throughout the world. Repercussions have been felt in science, industry, education, government, law, ethics, and religion. No area of human activity or thought has escaped. The toys of our children, the ambitions of our young men and women, the fortunes of industrialists, the daily tasks of diplomats, the careers of military officers, the pronouncements of high church officials—all have reflected the all-pervading influence of the beginning steps in space exploration. The impact can only be compared with those great developments of past history like the Copernican theory which placed the Sun, rather than the earth, at the center of our solar system; to the work of Sir Isaac Newton in relating the fall of an apple to the motion of the moon around the earth through the universal law of gravitation: to the industrial revolution; or to other great landmarks in the history of mankind.[19]

# FOOTNOTES, SOURCES AND BIBLIOGRAPHY, APPENDIXES, AND INDEX

# Footnotes

## *Chapter I*

[1] See Gertrude and James Jobes, *Outer Space: Myths, Name Calendars, Meanings: From the Emergence of History to the Present Day* (New York, 1964).

[2] For the long history of space travel fiction see Marjorie Hope Nicolson, *Voyages to the Moon* (paperback ed., New York, 1960), and *Science and Imagination* (Ithaca, N.Y., 1965); Willy Ley, *Rockets, Missiles, and Space Travel* (Rev. ed., New York, 1957), 9–40; Arthur C. Clarke, "Space Travel in Fact and Fiction," *Journal of the British Interplanetary Society*, IX (Sept. 1950), 213–230; James O. Bailey, *Pilgrims Through Space and Time: Trends and Patterns in Scientific and Utopian Fiction* (New York, 1957); Roger L. Green, *Into Other Worlds: Space-Flight from Lucian to Lewis* (New York, 1958); Philip B. Gove, *The Imaginary Voyage in Prose and Fiction: A History of Its Criticism and a Guide to Its Study . . .* (New York, 1961); John Lear, *Kepler's Dream* (Berkeley, Calif., 1965); and W. R. Maxwell, "Some Aspects of the Origins and Early Development of Astronautics," *Journal of the British Interplanetary Society*, XVIII (Sept. 1962), 415–425.

[3] Edward Everett Hale, "The Brick Moon," *Atlantic Monthly*, XXIV (Oct., Nov., Dec., 1869), 451–460, 603–611, 679–688. Also published in Hale, *The Brick Moon and Other Stories* (New York, 1899). Hale is of course better known for another story, "The Man Without a Country."

[4] Good treatments of astronomical developments in the 16th, 17th, and 18th centuries are in A. R. Hall, *The Scientific Revolution, 1500–1800: The Foundation of the Modern Scientific Attitude* (Boston, 1954); and Alexandre Koyré, *From the Closed World to the Infinite Universe* (paperback ed., New York, 1958).

[5] Charles G. Abbot, *Great Inventions* (Washington, 1943), 227–229. On Langley's failure and the public reaction to it, see Mark Sullivan, *Our Times: The United States, 1900–1925*, Vol. II: *America Finding Herself* (New York, 1927), 562–564. In 1914, after numerous modifications and largely as an attempt to invalidate the Wright Brothers' patents, Glen H. Curtiss flew the Langley aerodrome successfully with pontoons. Fourteen years later the Smithsonian reconciled itself to the fact the Wrights' airplane of 1903 was the first successful flying machine, rather than Langley's aerodrome. See Abbot, "The Relations between the Smithsonian Institution and the Wright Brothers," *Smithsonian Miscellaneous Collections*, LXXXI (Sept. 29, 1928).

[6] Orville Wright, quoted in N. H. Randers-Pehrson, *History of Aviation* (New York, 1944), 36. For a description of the flight, see Elsbeth E. Freudenthal, *Flight into History: The Wright Brothers and the Air Age* (Norman, Okla., 1949), 3–90; Marvin W. McFarland, ed., *The Papers of Wilbur and Orville Wright . . .* (2 vols., New York, 1953), I, 395–397; and Charles H. Gibbs-Smith, "The Wright Brothers and Their Invention of the Practical Aeroplane," *Nature*, CXCVIII (June 1, 1963), 824–826.

[7] There are several reasonably good histories of aviation and aeronautical research, including M. J. B. Davy, *Interpretive History of Flight* (London, 1948); Charles H. Gibbs-Smith, *The History of Flying* (New York, 1954) and *The Aeroplane* (London, 1960); Lloyd Morris and Kendall Smith, *Ceiling Unlimited: The Story of American Aviation from Kitty Hawk to Supersonics* (New York, 1953); Theodore von Kármán, *Aerodynamics: Selected Topics in the Light of Their Historical Development* (Ithaca, N.Y., 1954); and R. Giacomelli, "Historical Sketch," in William F. Durand, ed., *Aerodynamic Theory: A General Review of Progress* (2 ed., 6 vols. in 3, New York, 1963), I, 304–394. See also Hunter Rouse and Simon Ince, *History of*

*Hydraulics* (Iowa City, Iowa, paperback ed., New York, 1963), 229–242.

[8] Jerome C. Hunsaker, "Forty Years of Aeronautical Research," *Report of the Smithsonian Institution for 1955* (Washington, 1956), 241–251; Arthur S. Levine, "United States Aeronautical Research Policy, 1915–1958: A Study of the Major Policy Decisions of the National Advisory Committee for Aeronautics," unpublished Ph. D. dissertation, Columbia University, 1963, 7–16; George W. Gray, *Frontiers of Flight: The Story of NACA Research* (New York, 1948), 9–15; A. Hunter Dupree, *Science in the Federal Government: A History of Policies and Activities to 1940* (Cambridge, Mass., 1957), 283–287; John F. Victory, "The NACA: Cradle of Research," *Flying*, LX (March 1957), 40–43. In 1921, NACA installed at Langley a pioneering variable-density wind tunnel, which featured the use of compressed air to produce an airflow over small models, thus closely simulating the flow over full-scale aircraft.

[9] Hunsaker, "Forty Years of Aeronautical Research," 251–254; Levine, "U.S. Aeronautical Research Policy," 7–41. The passage in 1926 of the Air Commerce Act, which made the Secretary of Commerce responsible for encouraging and regulating civil aviation, clarified the role of NACA and made possible the focus on aeronautical research.

[10] The great majority of the people who joined the research staff of NACA during the history of the organization, 1915–1958, held degrees in engineering rather than the physical sciences. Thus "research engineer" became the most common formal designation for those working in aeronautical science for NACA.

[11] Gray, *Frontiers of Flight*, 33–70; Hunsaker, "Forty Years of Aeronautical Research," 254–259. The classic text on subsonic aerodynamics is Richard von Mises, *Theory of Flight* (2 ed., New York, 1959).

[12] Elsbeth E. Freudenthal, *The Aviation Business: Kitty Hawk to Wall Street* (New York, 1940), 62–304; John B. Rae, "Financial Problems of the American Aircraft Industry," *Business History Review*, XXXIX (spring 1965), 99–114.

[13] By 1938 the altitude record set for aircraft, as established by an Italian aviator, had reached beyond 56,000 feet. Eugene M. Emme, *Aeronautics and Astronautics: An American Chronology of Science and Technology in the Exploration of Space, 1915–1960* (Washington, 1961), 162.

[14] Hunsaker, "Forty Years of Aeronautical Research," 262.

[15] Levine, "U.S. Aeronautical Research Policy," 74–79; *Twenty-third Annual Report of the National Advisory Committee for Aeronautics—1937* (Washington, 1938), 2. The NACA organizational structure, in addition to the 15-member Main Committee, which established the research policies of the agency, and the various field installations, eventually included four technical committees, charged with studying problems in particular areas of aeronautical science and recommending to the Main Committee changes in policy and practice. The membership of the various technical committees, like that of the Main Committee, came from the military, the aircraft industry, and the academic community. Each of the technical committees had subcommittees. In 1957 the technical committees were: Aerodynamics, Power Plants, Aircraft Construction, and Operating Problems. See *Forty-third Annual Report of NACA—1957* (Washington, 1957).

[16] Gray, *Frontiers of Flight*, 19–33; Hunsaker, "Forty Years of Aeronautical Research," 261–262.

[17] Nicholas J. Hoff and Walter G. Vincenti, eds., *Aeronautics and Astronautics: Proceedings of the Durand Centennial Conference Held at Stanford University, 5–8 August, 1959* (New York, 1960), 16.

[18] Edgar Buckingham, "Jet Propulsion for Airplanes," in NACA Report No. 159, in *Ninth Annual Report of NACA—1923* (Washington, 1924), 75–90.

[19] Hunsaker, "Forty Years of Aeronautical Research," 266–267; Levine, "U.S. Aeronautical Research Policy," 81–89.

[20] See Robert L. Perry, "The Antecedents of the X–1," paper, American Institute of Aeronautics and Astronautics, San Francisco, July 26–28, 1965, 2–17; and Ley, *Rockets, Missiles, and Space Travel*, 411–413.

[21] Hunsaker, "Forty Years of Aeronautical Research," 267. See also John B. Rae, "Science and Engineering in the History of Aviation," *Technology and Culture*, III (fall 1961), 391–399. Hunsaker, head of the Department of Aeronautical Engineering at the Massachusetts Institute of Technology and a member of the Main Committee since the 1930s, assumed the chairmanship of NACA in 1941 on Bush's resignation.

[22] On the role of air power in the Second World War, see Eugene M. Emme, "The Im-

pact of Air Power Upon History," *Air University Quarterly Review,* II (winter 1948), 3–13; Eugene M. Emme, ed., *The Impact of Air Power: National Security and World Politics* (Princeton, N.J., 1959), 209–294; and Wesley F. Craven and James L. Cate, eds., *History of the Army Air Forces in World War II* (7 vols., Chicago, 1948–1955).

[23] See C. Fayette Taylor, "Aircraft Propulsion: A Review of the Evolution of Aircraft Powerplants," *Report of the Smithsonian Institution for 1961* (Washington, 1962), 245–298.

[24] The best-known of these advisory groups was the so-called von Kármán Committee, established late in 1944 at the direction of Henry H. Arnold, Commanding General of the Army Air Forces, and headed by Theodore von Kármán, of the California Institute of Technology. After surveying wartime achievements in aeronautical science and rocketry, the panel of scientists published its findings in August 1945 and its recommendations in December. While giving full credit to the German accomplishments in rocketry, the von Kármán committee concluded that jet propulsion offered the key to "air supremacy," and that progress toward long-range ballistic missiles should come through the development of air-breathing pilotless aircraft. The philosophy embodied in these 14 reports was to guide Air Force thinking for almost 10 years. See Army Air Forces Scientific Advisory Group, *Toward New Horizons: A Report to General of the Army H. H. Arnold* (14 vols. [Washington], 1945). For a retrospect of the findings of the committee, see Hugh L. Dryden, "Toward the New Horizons of Tomorrow: First Annual ARS von Kármán Lecture," *Astronautics,* XII (Jan. 1963), 14–19. Dryden served as deputy scientific director to von Kármán on the committee.

[25] Levine, "U.S. Aeronautical Research Policy," 91–97; Hunsaker, "Forty Years of Aeronautical Research," 267–268.

[26] The unitary plan was designed to provide dispersed NACA-Air Force wind-tunnel facilities characterized by a minimum of overlap and a maximum of variety. Five new supersonic wind tunnels were constructed, one at each of the NACA laboratories and two at a new Air Force installation, the Arnold Engineering Development Center at Tullahoma, Tenn. See *Manual for Users of the Unitary Plan Wind Tunnel Facilities* (Washington, 1956); and Alan Pope, *Wind-Tunnel Testing* (2 ed., New York, 1954).

[27] Axel T. Mattson, interview, Houston, July 2, 1964; Gray, *Frontiers of Flight,* 330–359; Frank Waters, *Engineering Space Exploration: Robert R. Gilruth* (Chicago, 1963), 38–39; "History of NACA Transonic Research," Langley Aeronautical Laboratory, undated copy in Archives of the Manned Spacecraft Center (MSC), Houston. Unless otherwise indicated, originals or copies of all primary materials cited in this work are located in the MSC Archives.

The Langley engineers also pursued their transonic investigations with a method devised in 1944 by Gilruth, whereby small models of wings or complete aircraft were attached to the upper wing surface of an airplane, thus employing the accelerated airflow over the wing surface for studying the aerodynamic characteristics of the model at transonic speeds.

[28] Perry, "Antecedents of the X–1," 18–20; Kenneth S. Kleinknecht, "The Rocket Research Airplanes," in Eugene M. Emme, ed., *The History of Rocket Technology: Essays on Research, Development, and Utility* (Detroit, 1964), 193–198; Hunsaker, "Forty Years of Aeronautical Research," 268, 269; Gray, *Frontiers of Flight,* 334–336; Ley, *Rockets, Missiles, and Space Travel,* 419–432. Because of the fear that the X–1, operating with an entirely new rocket powerplant, might not be ready as early as planned, the NACA-Air Force-Navy group concurrently developed a jet-propelled research airplane, the Douglas D–558–1. This was also in keeping with NACA's original conviction, shared by the Navy, that the first research aircraft would be turbojet-powered.

[29] Kleinknecht, "Rocket Research Airplanes," 199–204; Ley, *Rockets, Missiles, and Space Travel,* 424–426; Charles V. Eppley, *The Rocket Research Aircraft Program, 1946–1962* (Edwards Air Force Base, Calif., 1962), 1–25; Hunsaker, "Forty Years of Aeronautical Research," 269; James A. Martin, "The Record-Setting Research Airplanes," *Aeronautical Engineering Review,* XXI (Dec. 1962), 49–54; Walter C. Williams and Hubert M. Drake, "The Research Airplane: Past, Present, and Future," *Aeronautical Engineering Review,* XVII (Jan. 1958), 36–41; Walter T. Bonney, "High-Speed Research Airplanes," *Scientific American,* CLXXXIX (Oct. 1953), 36–41. For the experiences of two rocket-airplane test pilots, as well as for useful treatments of the postwar research aircraft series, see A. Scott Crossfield and Clay Blair, *Always Another Dawn* (Cleveland, 1960); and William Bridgeman and Jacqueline Hazard, *The Lonely Sky* (New York, 1955).

[30] Probably the greatest NACA contribution to the century series (F–100, etc.) was a discovery made in 1951 by Richard T. Whitcomb, an aeronautical engineer working mainly in the recently opened 8-foot, slotted-throat tunnel at the Langley laboratory. Whitcomb collected data on the lengthwise distribution of fuselage and wing volume and suggested an airplane configuration that minimized drag at supersonic speeds. Whitcomb's findings, known as the "area rule," indicated that a coke-bottle, or wasp-waisted, shape would significantly increase the speed of jet-propelled airplanes. The importance of the area rule was reflected in the configuration of practically every jet interceptor designed and built for both the Air Force and the Navy in the mid-1950s. See Richard T. Whitcomb, "A Study of the Zero-Lift Drag-Rise Characteristics of Wing-Body Combinations Near the Speed of Sound," NACA Tech. Report 1273, *Forty-Second Annual Report of the NACA–1956* (Washington, 1957), 519–539.

[31] Discussions of the principles of rocketry can be found in many places, but some of the most lucid explanations from the layman's standpoint are in Ley, *Rockets, Missiles, and Space Travel*, 60–65; Erik Bergaust and Seabrook Hull, *Rocket to the Moon* (Princeton, N.J., 1958), 33–43; Ralph S. Cooper, "Rocket Propulsion," *Report of the Smithsonian Institution for 1962*, 299–313; and Andrew G. Haley, *Rocketry and Space Exploration* (Princeton, N.J., 1958), 33–43. See also NASA news release, unnumbered, "Liquid Propellant Rocket Engines," Jan. 1962. Equally informative as an introduction to rocketry but historically important as a spur to enthusiasts was G. Edward Pendray's *The Coming Age of Rocket Power* (New York, 1945), wherein rocket efficiency was pictured as opening "the way to an entire new world of velocities, altitudes, and powers which have hitherto been closed to us; and consequently to a whole new world of human experiences and possibilities" (p. 9).

[32] See A. A. Blagonravov, ed., *Collected Works of K. E. Tsiolkovsky*, Vol. II: *Reactive Flying Machines*, NASA TT F–237 (Washington, 1965).

[33] For biographical information on Tsiolkovsky, see A. Kosmodemyansky, *Konstantin Tsiolkovsky, His Life and Work*, trans. X. Danko (Moscow, 1956); Albert Parry, *Russia's Rockets and Missiles* (Garden City, N.Y., 1960), 94–104; Beryl Williams and Samuel Epstein, *The Rocket Pioneers on the Road to Space* (New York, 1955), 52–69; Heinz Gartmann, *The Men Behind the Space Rockets* (New York, 1956), 26–35; and K. E. Tsiolkovsky, "An Autobiography," trans. A. N. Petroff, *Astronautics*, IV (May 1959), 48–49, 63–64; V. N. Sokolskiy, "The Works of the Russian Scientist-Pioneers of Rocket Technology," in T. M. Melkumov, ed., *Pioneers of Rocket Technology* (Moscow, 1964), NASA TT F–9285 (Washington, 1965), 125–162.

[34] Biographical material on Goddard, little known outside of scientific circles until recent years, is accumulating rapidly. A valuable but not definitive biography is Milton Lehman, *This High Man: The Life of Robert H. Goddard* (New York, 1963). See also E. R. Hagemann, "Goddard and His Early Rockets: 1882–1930," *Journal of the Astronautical Sciences*, VII (Summer 1961), 51–59; Eugene M. Emme, "Yesterday's Dream—Today's Reality," *Air Power Historian*, VII (Oct., 1960), 216–221; G. Edward Pendray, "Pioneer Rocket Development in the United States," in Emme, *The History of Rocket Technology*, 19–23; also published in *Technology and Culture*, IV (Fall 1963), 384–388; Williams and Epstein, *Rocket Pioneers*, 70–110; Shirley Thomas, *Men of Space* (6 vols., Philadelphia, 1960–1963), I, 23–46; Gartmann, *Men Behind the Space Rockets;* and Emme, *A History of Space Flight* (New York, 1965), 85–87.

[35] Goddard's 1920 Smithsonian Institution report and a less famous report to the Smithsonian summarizing his findings to 1936 are in Robert H. Goddard, *Rockets, Comprising "A Method of Reaching Extreme Altitudes"* and *"Liquid-Propellant Rocket Development"* (New York, 1946). A condensation of Goddard's notebooks is Esther C. Goddard and G. Edward Pendray, eds., *Rocket Development: Liquid-Fuel Rocket Research, 1929–1941* (New York, 1961). The eastern daily newspapers seized on Goddard's "moon-rocket" reference in his first Smithsonian paper and blew it completely out of proportion. Some journals, having no conception of the mechanics of rocketry, even ridiculed the idea that a rocket could ascend into space, because in a vacuum it would have nothing to "react against." See, for example, the lead editorial in *New York Times*, Jan. 13, 1920. The storm of embarrassing publicity doubtless abetted the aversion to notoriety that characterized Goddard throughout his career.

[36] Pendray, "Pioneer Rocket Development in the United States," 21–23; Pendray, *The*

*Coming of Age of Rocket Power*, 35–43; Ley, *Rockets, Missiles, and Space Travel*, 443.

[37] Pendray, "Pioneer Rocket Development in the United States," 23–24; Pendray, "The First Quarter Century of the American Rocket Society," *Jet Propulsion*, XXV (Nov. 1955), 586–593.

[38] Frank J. Malina, "Origins and First Decade of the Jet Propulsion Laboratory," in Emme, ed., *History of Rocket Technology*, 52–54.

[39] *Ibid.*, 46–66; Haley; *Rocketry and Space Exploration*, 97–99; Ley, *Rockets, Missiles, and Space Travel*, 249–250, 436, 438; Perry, "Antecedents of the X–1," 20–23.

[40] An exception to the pattern of private sponsorship of rocket societies was the "Group for the Study of Rocket Propulsion Systems," known as GIRD, established under government auspices in the Soviet Union in 1931. House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), House Report No. 67, *A Chronology of Missile and Astronautic Events*, 3; G. A. Tokaty, "Soviet Rocket Technology," in Emme, ed., *History of Rocket Technology*, 275–276; also published in *Technology and Culture*, IV (Fall 1963), 520–521.

[41] On Oberth see Williams and Epstein, *Rocket Pioneers*, 111, 143; Gartmann, *Men Behind the Space Rockets;* Ley, *Rockets, Missiles, and Space Travel*, 108–130; William Meyer-Cords, "Introduction" to Hermann Oberth, *Man into Space: New Projects for Rocket and Space Travel*, trans. G. P. H. deFreville (New York, 1957), vii–xiv; Hermann Oberth, "From My Life," *Astronautics*, IV (June 1959), 38–39, 100–104; and G. V. E. Thompson, "Oberth—Doyen of Spaceflight Today," *Spaceflight*, I (Oct. 1957), 170–171.

[42] Ley, *Rockets, Missiles, and Space Travel*, 118–162, 197–201; Walter Dornberger, "The German V–2," in Emme, ed., *History of Rocket Technology*, 29–33; also published in *Technology and Culture*, IV (Fall 1963), 394–395. Williams and Epstein, *Rocket Pioneers*, 144–170. Von Braun received a doctorate in physics from the University of Berlin in 1934.

[43] See Walter Dornberger, *V–2* (New York, 1954); Dornberger, "The German V–2," 33–45; Williams and Epstein, *Rocket Pioneers*, 204–231; Ley, *Rockets, Missiles, and Space Travel*, 202–231; Dieter K. Huzel, *Peenemünde to Canaveral* (Englewood Cliffs, N.J., 1962); Leslie G. Simon, *German Research in World War II: An Analysis of the Conduct of Research* (New York, 1947), 33–35; and Theodore Benecke and A. W. Quick, eds., *History of German Guided Missiles* (Brunswick, Ger., 1957).

[44] Ley, *Rockets, Missiles, and Space Travel*, 212–217; Kurt H. Debus, "Evolution of Launch Concepts and Space Flight Operations," in Ernst Stuhlinger, Frederick I. Ordway III, Jerry C. McCall, and George C. Bucher, eds., *From Peenemünde to Outer Space: Commemorating the Fiftieth Birthday of Wernher von Braun* (Huntsville, Ala., 1962), 45. During the powered phase of its flight within the atmosphere the V–2 was stabilized by large aerodynamic fins.

[45] *Chronology of Missile and Astronautic Events*, 7; Dornberger, "The German V–2," 32–33. "Vengeance Weapon No. 1"—V–1—was a radio-controlled, subsonic guided missile powered by a pulsejet engine, developed by the German Air Force. Besides the A–4, the accomplishments of the Peenemünde rocket workers included the launching in the early part of 1945 of a winged A–4, called the A–9, which they had designed as the upper stage of a rocket to attack the United States. And by the end of the war Eugen Sänger, already well-known as an Austrian rocket scientist before going to work for the Luftwaffe, and Irene Bredt, a noted German physicist, had written an elaborate report containing a design for an antipodal rocket bomber that would skip in and out of the atmosphere to drop its payload and land halfway around the world. See also Eugen Sänger, *Rocket Flight Engineering*, NASA TT F–223 (Washington, 1965).

[46] Senate Preparedness Subcommittee of the Committee on Armed Services, 85 Cong., 1 and 2 sess. (1957–58), *Inquiry into Satellite and Missile Programs, Hearings*, testimony of Wernher von Braun, Part 1, 850; David S. Akens, *Historical Origins of the George C. Marshall Space Flight Center* (Huntsville, Ala., 1960), 24–29; Tokaty, "Soviet Rocket Technology," 278–279; James McGovern, *Crossbow and Overcast* (New York, 1964); Clarence G. Lasby, "German Scientists in America: Their Importation, Exploitation, and Assimilation, 1945–1952," unpublished Ph. D. dissertation, University of California at Los Angeles, 1962. All together, Paperclip brought nearly 500 aeronautical and rocket scientists, engineers, and technicians to the United States.

[47] Quoted in Tokaty, "Soviet Rocket Technology," 279.

[48] *Inquiry into Satellite and Missile Pro-*

*grams,* testimony of von Braun, Part 1, 581; Parry, *Russia's Rockets and Missiles,* 118–125.

[49] James P. Baxter, *Scientists Against Time* (Boston, 1946), 201.

[50] Quoted in Tokaty, "Soviet Rocket Technology," 281.

[51] *Ibid.,* 282–283; Parry, *Russia's Rockets and Missiles,* 131–133; Frederick I. Ordway III, and Ronald C. Wakeford, *International Missile and Spacecraft Guide* (New York, 1960), 3–4; Donald J. Ritchie, "Soviet Rocket Propulsion," in Donald P. LeGalley, ed., *Ballistic Missile and Space Technology,* Vol. II: *Propulsion and Auxiliary Power Systems* (New York, 1960), 55–85; *Chronology of Missile and Astronautic Events,* 26; Charles S. Sheldon II, "The Challenge of International Competition," paper, Third American Institute of Aeronautics and Astronautics/NASA Manned Space Flight Meeting, Houston, Nov. 6, 1964.

[52] Among the air-breathing guided missiles (a term that simply meant any pilotless flying craft) designed and developed by the Navy and the Air Force in the first decade after the war were the Gorgon, Plover, Regulus, Cobra, Bomarc, Snark, Matador, and Loon, the last being a Navy version of the German V–1. Of these weapons only the Snark was a genuinely long-range, or intercontinental, missile, and it was subsonic and thus vulnerable to radar-controlled antiaircraft rockets. See Ordway and Wakeford, *International Missile and Spacecraft Guide,* 3–5, 8–9, 15–16, 20–24, 26, 61.

[53] Quoted, among many other places, in *Inquiry into Satellite and Missile Programs,* Part I, 283. For a more lengthy argument against early attempts to develop intercontinental ballistic missiles, see Vannevar Bush, *Modern Arms and Free Men* (New York, 1949).

[54] See Kenneth W. Gatland, *Development of the Guided Missile* (London, 1954); and Nels A. Parsons, *Guided Missiles in War and Peace* (Cambridge, Mass., 1956), and *Missiles and the Revolution in Warfare* (Cambridge, Mass., 1962).

[55] On the postwar V–2 program at White Sands and Cape Canaveral, see U.S. Army Ordnance Corps/General Electric Co., *Hermes Guided Missile Research and Development Project, 1944–1954* (Sept. 25, 1959), 1–4; Ley, *Rockets, Missiles, and Space Travel,* 254–271; Akens, *Historical Origins of the Marshall Space Flight Center,* 28–35; Ernest Krause, "High Altitude Research with V–2 Rockets," *Proceedings of the American Philosophical Society,* XCI (1947), 430–446; and J. Gordon Vaeth, *200 Miles Up: The Conquest of the Upper Air* (2 ed., New York, 1956), 117–134. Unless otherwise indicated, all mileage figures used in this work refer to statute miles.

On Thanksgiving Day 1963, several months after Project Mercury officially ended, President Lyndon B. Johnson renamed Cape Canaveral, Cape Kennedy. Since that is beyond the historical context of this study, throughout the rest of this work Cape Canaveral will be used.

[56] *Ibid.,* 178–194; Homer E. Newell, *Sounding Rockets* (New York, 1959), 54–95; Emme, *Aeronautics and Astronautics,* 53–54, 58–59, 63, 67, 69–70, 77.

[57] On the Viking see Ley, *Rockets, Missiles, and Space Travel,* 271–276; Milton Rosen, *The Viking Rocket Story* (New York, 1955); John P. Hagen, "The Viking and the Vanguard," in Emme, ed., *History of Rocket Technology,* 123–125; also published in *Technology and Culture,* IV (Fall 1963), 436–437; Vaeth, *200 Miles Up,* 195–206; and Newell, *Sounding Rockets,* 235–242. The first Viking shot, fired in May 1950 from the deck of the *Norton Sound* in the Pacific, set a new single-stage altitude record, 106.6 miles.

[58] On the Navaho see Ordway and Wakeford, *International Missile and Spacecraft Guide,* 9–10; and Emme, *Aeronautics and Astronautics,* 64, 70, 72, 74, 76, 77, 86. Besides booster development, the technological heritage from the Navaho program included the airframe for the Hound Dog air-to-surface missile, progress in using titanium for structures, and the guidance system for nuclear-powered submarines.

[59] Akens, *Historical Origins of the Marshall Space Flight Center,* 36–37; Wernher von Braun, "The Redstone, Jupiter, and Juno," in Emme, ed., *History of Rocket Technology,* 108–109; also published in *Technology and Culture,* IV (Fall 1963), 452–455; A. A. McCool and Keith B. Chandler, "Development Trends in Liquid Propellant Engines," in Stuhlinger, Ordway, McCall, and Bucher, eds., *From Peenemünde to Outer Space,* 292; John W. Bullard, "History of the Redstone Missile System," Hist. Div., Army Missile Command, Oct. 1965, 135–151. The creation of the North Atlantic Treaty Organization in 1949 had provided a clear military need for a battlefield rocket.

[60] *Jane's All the World's Aircraft, 1962–1963* (London, 1963), 391–392; von Braun,

"The Redstone, Jupiter, and Juno," 109–110; McCool and Chandler, "Development Trends in Liquid Propellant Engines," 292: Bullard, "History of the Redstone," 53–93.

[61] The term "ballistic missile" refers to a projectile fired along a ballistic, or high-arc, trajectory, reaching an altitude of several hundred miles before falling freely toward its target. Such a vehicle is to be distinguished from the jet-propelled guided missile, which is controlled throughout its flight, requires oxygen within the air for its propellant oxidizer, and can operate only within the atmosphere. Thus by definition a ballistic missile, which reaches well into space, is a rocket.

[62] John L. Chapman, *Atlas: The Story of a Missile* (New York, 1960), 30–54: *Inquiry into Satellite and Missile Programs,* testimony of James R. Dempsey, Part 2, 1871–1872.

[63] Chapman, *Atlas,* 60–62; *Inquiry into Satellite and Missile Programs,* testimony of Dempsey, Part 2, 1872; Robert L. Perry, "The Atlas, Thor, Titan, and Minuteman," in Emme, ed., *History of Rocket Technology,* 143; also published as "The Atlas, Thor, and Titan," in *Technology and Culture,* VI (Fall 1963), 467.

[64] House Select Committee on Astronautics and Space Exploration, 85 Cong., 2 sess. (1958), *Astronautics and Space Exploration, Hearings,* testimony of Bernard A. Schriever, 668; Chapman, *Atlas,* 70–74; Bernard A. Schriever, "The USAF Ballistic Missile Program," in Kenneth F. Gantz, ed., *The United States Air Force Report on the Ballistic Missile* (Garden City, N.Y., 1958), 2–28; House Committee on Government Operations, 86 Cong., 1 sess. (1959), House Report No. 1121, *Organization and Management of Missile Programs,* 70–71; Ernest G. Schwiebert, *A History of the U.S. Air Force Ballistic Missiles* (New York, 1965), 67–73.

[65] *Astronautics and Space Exploration,* testimony of Schriever, 668. See also, Herman Kahn, *On Thermonuclear War* (Princeton, N.J., 1961), and *Thinking about the Unthinkable* (New York, 1962).

[66] See Schwiebert, *Air Force Ballistic Missiles,* 75–95.

[67] On this point Schriever elaborated: "I think the Air Force philosophy of having industry do development and having the capability of planning for production simultaneously is a much better way. . . . The Air Force had quite a number of German scientists right after the war at Wright Field, and made, deliberately made, the decision not to try to retain that group of scientists as a group, similar to what they have done at Redstone, and . . . most of them have gone into American industry. . . . They are at Convair, they are at Bell, and a number of other companies, and . . . my feeling is that these people, distributed to American industry, are doing equally as good a job for the United States as this one small group that are still assembled at the Redstone Arsenal." *Inquiry into Satellite and Missile Programs,* Part 2, testimony of Schriever, 1637–1638.

[68] Chapman, *Atlas,* 74, 78; Schriever, "USAF Ballistic Missile Program," 28; Perry, "Atlas, Thor, Titan, and Minuteman," 144–148; *Organization and Management of Missile Programs,* 73–79; Thomas, *Men of Space,* II, 143–149. The Ramo-Wooldridge Corporation was established by Simon Ramo and Dean Wooldridge, missile experts who, as employees of the Hughes Aircraft Company, had served on the Teapot Committee. They left Hughes in 1953 to set up their missiles research and management firm. For a description of the role of Space Technology Laboratories in the American missile effort and a critique of the STL/Air Force arrangement, see *Organization and Management of Missile Programs,* 81–100. In 1958 the Ramo-Wooldridge Corporation merged completely with an initial financial backer, the Thompson Products Company of Cleveland, to form the Thompson Ramo Wooldridge Corporation. See Robert Sheehan, "Thompson Ramo Wooldridge: Two Wings in Space," *Fortune,* LXVII (Feb. 1963), 95–99ff.

[69] *Inquiry into Satellite and Missile Programs,* Part I, 471; Wyndam D. Miles, "The Polaris," in Emme, ed., *History of Rocket Technology,* 164–166; also published in *Technology and Culture,* VI (Fall 1963), 480–482. The competition deliberately established by the Defense Department between the Air Force and the Army over the Thor and the Jupiter, while perhaps necessary, proved intense, acrimonious, and apparently wasteful. The full story of the Thor-Jupiter rivalry in the period 1955–1958 is yet to be told, but some valuable insight can be gained from *Organization and Management of Missile Programs,* 101–116. An account heavily biased in favor of the Army is John B. Medaris, *Countdown for Decision* (New York, 1960), 86–150. The Air Force side of the story is presented in Julian Hartt, *The Mighty Thor: Missile in Readiness* (New York, 1961).

[70] Perry, "Atlas, Thor, Titan, and Minuteman," 148. On concurrency see also Schriever, "USAF Ballistic Missile Program," 30–39; and Osmond J. Ritland, "Concurrency," *Air*

*University Quarterly Review,* XII (Winter-Spring 1960–1961), 237–250. Parallel development of components had characterized numerous advances in 20th-century science and technology, of course, notably the Manhattan Project that produced the atomic bomb in the Second World War. (See Baxter, *Scientists Against Time,* 419–447; and Richard G. Hewlett and Oscar E. Anderson, *A History of the United States Atomic Energy Commission,* Vol. I: *The New World, 1939–1946* [University Park, Pa., 1962], 9–407.) But "concurrency" as a formal research and engineering management technique is properly credited to the Air Force ballistic missile program of the fifties.

[71] Perry, "Atlas, Thor, Titan, and Minuteman," 149–150. The Strategic Air Command assumed operational planning responsibility for all intermediate and intercontinental missiles in 1958.

[72] Chapman, *Atlas,* 88–89; *Jane's All the World's Aircraft, 1962–1963,* 394. On the intricacies involved in fabricating the extremely thin Atlas airframe, see Robert Sweeney, "Atlas Generates Fabrication Advances," *Aviation Week,* LXXII (Jan. 4, 1960), 38–49; and "Manufacturing the Atlas at Convair," *Interavia,* LXXI (1959), 810–811.

[73] Chapman, *Atlas,* 136–137; *Jane's All the World's Aircraft, 1962–1963,* 394; Ordway and Wakeford, *International Missile and Spacecraft Guide,* 1–3; NASA/MSC news release, "The Mercury-Atlas 8 Launch Vehicle," Oct. 1, 1962; C. L. Gandy and I. Hanson, "Mercury-Atlas Launch-Vehicle Development and Performance," in *Mercury Project Summary, Including Results of the Fourth Orbital Flight, May 15 and 16, 1963* (Washington, 1963), 84–91. On Rocketdyne's problems in developing the powerplant for the Atlas see Thomas F. Dixon, "Development Problems of Rocket Engines for Ballistic Missiles," *Interavia,* LXXI (1959), 818–821.

[74] Ordway and Wakeford, *International Missile and Spacecraft Guide,* 1–3; *Jane's All the World's Aircraft, 1962–1963,* 395.

[75] Chapman, *Atlas,* 81–82; Gandy and Hanson, "Mercury-Atlas Launch-Vehicle Development and Performance," 91–92; *Jane's All the World's Aircraft, 1962–1963,* 394–395; Ordway and Wakeford, *International Missile and Spacecraft Guide,* 2. Beginning in late 1960 with the "E" version, the guidance system of the Atlas became all-inertial, meaning that all guidance components were carried aboard the rocket. General Electric and Burroughs Corp. developed the radio-inertial guidance system for the Atlas, while the American Bosch Arma Corp. produced the all-inertial system.

[76] Atmospheric entry heating was not a critical problem for the medium-range (200-mile) Redstone, which did not develop the velocities of the intermediate and intercontinental rockets. Thus protecting the astronaut during the reentry phase of the suborbital (Redstone) flights in Project Mercury, while deserving attention, was not of acute concern.

[77] Von Kármán, *Aerodynamics,* 189. In view of the continually modifying nature of astronautical terminology, the authors throughout this work have used the terms "entry" and "reentry" interchangeably. They realize that some aerodynamicists make a distinction between the two.

[78] Colonel Oleg Penkovsky, the now-famous Russian "master spy" for the West in the Soviet intelligence system, supposedly wrote as late as the first part of 1962: "Only the smaller (IRBM) missiles are in production. . . . Right now we have a certain number of missiles with nuclear warheads capable of reaching the United States or South America; but these are single missiles, not in mass production, and they are far from perfect." (Frank Gibney, ed., *The Penkovsky Papers,* trans. Peter Deriabin [Garden City, N.Y., 1965], 331–348.) Thus while the Soviets may have been able to fire an ICBM over its design range before the United States and use it to launch relatively heavy satellites, they apparently had great troubles producing such a military rocket in quantity, as the United States was doing by 1962 with its Atlas, Titan, and Minuteman.

[79] House Committee on Science and Astronautics, 86 Cong., 2 sess. (1960), House Report No. 2092, *Space, Missiles, and the Nation,* 5–7; *Organization and Management of Missile Programs,* 108–109.

[80] *Inquiry into Satellite and Missile Programs,* testimony of J. H. Kindelberger, Part 1, 1280.

[81] *Astronautics and Space Exploration,* testimony of Schriever, 669.

[82] Parry, *Russia's Rockets and Missiles,* 141; Ordway and Wakeford, *International Missile and Spacecraft Guide,* 3–4; Ritchie, "Soviet Rocket Propulsion," 71; Alfred Z. Zachringer, "Table of Soviet Missiles," in F. J. Krieger, ed., *A Casebook on Soviet Astronautics* (2 vols.,

Santa Monica, Calif., 1956–1959), I, 242.

[83] Quoted in Parry, *Russia's Rockets and Missiles,* 111.

[84] Quoted in Mary Stone Ambrose, "The National Space Program," unpublished M.A. thesis, 2 vols., American University, 1960–1961, I, 17. See also Dwight D. Eisenhower, *The White House Years: Waging Peace, 1956–1961* (Garden City, N.Y., 1965). A useful anthology of official reactions to the Soviet space coup is Richard L. Witkin, ed., *The Challenge of the Sputniks* (New York, 1958).

[85] See R. Cargill Hall, "Early U.S. Satellite Proposals," in Emme, ed., *History of Rocket Technology,* 67–93; also published in *Technology and Culture,* VI (Fall 1963), 410–434.

[86] Memo, Albert E. Lombard, Scientific Advisor, Directorate of Research and Development, Department of the Air Force, to Committee on Aerodynamics, NACA, "Upper Stratosphere, Ionosphere, and Space Flight," June 25, 1952.

[87] Quoted in Parry, *Russia's Rockets and Missiles,* 184; and Krieger, ed., *Casebook on Soviet Astronautics,* II, 1.

[88] Parry, *Russia's Rockets and Missiles,* 185–186; *Astronautics and Space Exploration,* testimony of Andrew G. Haley, 1462–1463.

[89] Kreiger, ed., *Casebook on Soviet Astronautics,* II, 2–10; Parry, *Russia's Rockets and Missiles,* 186–188; *Astronautics and Space Exploration,* testimony of Haley, 1464.

[90] Hagen, "Viking and Vanguard," 137; John Lear, "The Moon That Refused to Be Eclipsed," *Saturday Review,* XLIII (March 5, 1963), 45–48; Kurt R. Stehling, *Project Vanguard* (Garden City, N.Y., 1961), 141–181.

[91] The controversial history of the decision to build a new satellite rocket based on the Viking and the Aerobee, as proposed by the Naval Research Laboratory, rather than to adapt the Redstone for the Geophysical Year satellite program, as proposed by the Office of Naval Research and the Army in Project Orbiter, is beyond the scope of this work. The Vanguard-Orbiter imbroglio is covered in von Braun, "Redstone, Jupiter, and Juno," 111–113; Carsbie C. Adams, *Space Flight* (New York, 1958), 112–113; E. Nelson Hayes, "The Smithsonian's Satellite Tracking Program: Its History and Organization," *Report of the Smithsonian Institution for 1961* (Washington, 1962), 275–322; *Astronautics and Space Exploration,* testimony of John T. Hayward, 293–294; *Inquiry into Satellite and Missile Programs,* testimony of James M. Gavin and J. B. Medaris, Part 2, 1473–1475, 1633–1634; Hagen, "Viking and Vanguard," 125–127; Akens, *Historical Origins of the Marshall Space Flight Center,* 38–40; Jay Holmes, *America on the Moon: The Enterprise of the Sixties* (Philadelphia, 1962), 46–51; and R. Cargill Hall, "Origins and Development of the Vanguard and Explorer Satellite Programs," *Air Power Historian,* XI (Oct. 1964).

[92] After losing out in the satellite rocket competition, the Army engineers at Redstone Arsenal had stubbornly sought authorization to reactivate their satellite project. Rebuffed in the Defense Department, the Army group shrewdly renamed a modified Redstone, which they were preparing for tests of the Jupiter reentry nose cone, the Jupiter-C, in order to continue receiving funds for the satellite project. See von Braun, "Redstone, Jupiter, and Juno," 113–114; *Inquiry into Satellite and Missile Programs,* testimony of J. B. Medaris, Part 2, 1700–1701; Medaris, *Countdown for Decision;* James M. Gavin, *War and Peace in the Space Age* (New York, 1958); *Astronautics and Space Exploration,* testimony of Gavin, 183–184; Akens, *Historical Origins of the Marshall Space Flight Center,* 40–44; *Organization and Management of Missile Programs,* 130.

[93] Akens, *Historical Origins of the Marshall Space Flight Center,* 44–50; von Braun, "Redstone, Jupiter, and Juno," 114; Bullard, "History of the Redstone," 142–146; Lear, "Moon That Refused to Be Eclipsed," 47; Hagen, "Viking and Vanguard," 448–451; Stehling, *Project Vanguard,* 182–219; House Committee on Science and Astronautics, 86 Cong., 1 sess. (1959), *U.S. Aeronautics and Space Activities, Jan. 1 to Dec. 31, 1958: Message from the President of the United States,* 3–4. On March 5, 1958, an attempt to launch *Explorer II* failed when th Jupiter-C fourth stage did not ignite.

[94] These four shots were made with the Atlas A, a version with a dummy sustainer engine and nose cone, designed solely for test purposes. The first Atlas A went out of control and was destroyed after less than a minute of flight on June 11, 1957, and a second attempt, on Sept. 25, ended in the same fashion. Success came on Dec. 17, 1957, when an Atlas A impacted on its target about 500 miles downrange from Cape Canaveral. On April 5, 1958, the test rocket flew successfully 600 miles downrange from the Cape. Chapman, *Atlas,* 118–133; Perry, "Atlas, Thor, Titan, and Minuteman," 151; George Alexander, "Atlas Accuracy Improves as Test Program is

Completed," *Aviation Week*, LXXVIII (Feb. 25, 1963), 57–58.

## *Chapter II*

[1] On advances in telemetry since the Second World War, see Wilfred J. Mayo-Wells, "The Origins of Space Telemetry," in Eugene M. Emme, ed., *The History of Rocket Technology: Essays on Research, Development, and Utility* (Detroit, 1964), 253–268; also published in *Technology and Culture*, IV (Fall 1963), 499–514.

[2] For the German work in aeromedicine during the 1930s and early 1940s, see U.S. Air Force, *German Aviation Medicine, World War II* (2 vols., Washington, 1950).

[3] Harry G. Armstrong, *Principles and Practices of Aviation Medicine* (3 ed., Baltimore, 1952). Armstrong later became a major general.

[4] Harry G. Armstrong, Heinz Haber, and Hubertus Strughold, "Aero Medical Problems of Space Travel, Panel Meeting, School of Aviation Medicine," *Journal of Aviation Medicine*, XIX (Dec. 1949), 383–417; Hubertus Strughold, interview, San Antonio, April 24, 1964. People interested in the physiology and psychology of extra-atmospheric flight have devised a number of terms to describe their field of investigation—biomedicine, space biology, astrobiology, bioastronautics, aerospace medicine. The most suitable single term seems to be that used by Strughold, "space medicine." It is used throughout this work except where more precise terminology, such as "biodynamics," appears appropriate.

[5] Shirley Thomas, *Men of Space* (6 vols., Philadelphia, 1960–1963), IV, 234–250; USAF Air Training Command, *History of the United States Air Force*, Pamphlet 190–1, Randolph Air Force Base, Tex., 1961, 19; Strughold interview. Siegfried J. Gerathewohl, a psychologist, and Hans-Georg Clamann, a physiologist, remained with the School of Aviation Medicine but did not become members of the Department of Space Medicine.

[6] Clayton S. White and Otis O. Benson, eds., *Physics and Medicine of the Upper Atmosphere: A Study of the Aeropause* (Albuquerque, 1952).

[7] Hubertus Strughold, "Basic Environmental Problems Relating Man and the Highest Regions of the Atmosphere as Seen by the Biologist," *ibid.*, 32. On the concept of space equivalence see also Strughold, Heinz Haber, Konrad Buettner, and Fritz Haber, "Where Does Space Begin? Functional Concept of the Boundaries between the Atmosphere and Space," *Journal of Aviation Medicine*, XXII (Oct., 1951), 342–357; Strughold, "Atmospheric Space Equivalence," *Journal of Aviation Medicine*, XXV (Aug., 1954), 420–424; Strughold, "The Medical Problems of Space Flight," *International Record of Medicine*, CLXVIII (1955), 570–575; and Strughold, "A Simple Classification of the Present and Future Stages of Manned Flight," *Journal of Aviation Medicine*, XXVII (Aug., 1956), 328–331.

[8] "Thirty-Five Years of Winged Rocket Flight," *Thiokol Magazine*, II (1963), 10; Hubertus Strughold, "Introduction," to Morton Alperin, M. Stern, and H. Wooster, eds., *Vistas in Astronautics: First Annual Astronautics Symposium* (London, 1958), 283.

[9] See Burt Rowen, "Human Factors Support of the X–15 Program," in Kenneth F. Gantz, ed., *Man in Space: The United States Air Force Program for Developing the Spacecraft Crews* (New York, 1959), 216–221; Stanley C. White, "Progress in Space Medicine," paper, Second World and Fourth European Aviation and Space Medicine Congress, Rome, Oct. 27–31, 1959; and Richard E. Day, "Training Aspects of the X–15 Program," in *The Training of Astronauts* (Washington, 1961), 5–14.

[10] Otto Gauer and Heinz Haber, "Man under Gravity-Free Conditions," in *German Aviation Medicine, World War II*, I, 641–643.

[11] David Bushnell, "History of Research in Subgravity and Zero-G at the Air Force Missile Development Center, 1948–1958," Air Force Missile Development Center, 1959, 3–7; David G. Simons, "Use of V–2 Rocket to Convey Primate to Upper Atmosphere," Air Force Tech. Report 5821, Air Materiel Command, Wright-Patterson Air Force Base, Ohio, May 1959; James P. Henry et al., "Animal Studies of the Subgravity State During Rocket Flight," *Journal of Aviation Medicine*, XXIII (Oct. 1952), 421–423; David G. Simons, interview, San Antonio, April 24, 1964. A breezy popular account of the Holloman shots with V–2s and Aerobees is Lloyd Mallan, *Men, Rockets, and Space Rats* (Rev. ed., New York, 1962), 84–116.

[12] Andrei G. Kousnetzov, "Some Results of Biological Experiments in Rockets and Sputnik II," *Journal of Aviation Medicine*, XXIX (Nov. 1958), 781–784; S. M. Polovskov and B. A. Mirtov, "Study of the Upper Atmosphere by Means of Rockets at the U.S.S.R. Academy of Sciences," and A. V. Pokrovskii, "Study of the Vital Activity of Animals during Rocket Flights in the Upper Atmosphere," in F. J.

Kreiger, ed., *A Casebook on Soviet Astronautics* (2 vols., Santa Monica, Calif., 1956–1959), II, 151–172; Siegfried J. Gerathewohl, *Principles of Bioastronautics* (Englewood Cliffs, N.J., 1964), 91–95.

[13] Harald J. von Beckh, "Human Reactions during Flight to Acceleration Preceded by or Followed by Weightlessness," *Aerospace Medicine*, XXX (June 1959), 391.

[14] Fritz Haber and Heinz Haber, "Possible Methods of Producing the Gravity-Free State for Medical Research," *Journal of Aviation Medicine*, XXI (Oct. 1950), 395–400.

[15] Allen C. Fisher, "Aviation Medicine on the Threshold of Space," *National Geographic*, CVI (Aug. 1955), 257; Siegfried J. Gerathewohl, "Weightlessness," in Gantz, ed., *Man in Space*, 115.

[16] *Ibid.*

[17] Bushnell, "Research in Subgravity and Zero-G at the Air Force Missile Development Center," 12–17; James H. Hanrahan and David Bushnell, *Space Biology: The Human Factors in Space Flight* (New York, 1960), 137, 139–140; Green Peyton and Jean Evans, "History, Aerospace Medical Division, Air Force Systems Command: Reorganization, 1 November 1961–30 June 1962," Hist. Publication 62–180, Brooks Air Force Base, Tex., 1962, 93–97.

[18] Hanrahan and Bushnell, *Space Biology*, 139–140; "USAF School Simulates Living in Space," *Aviation Week*, LXVIII (Jan. 27, 1958), 49–51; Siegfried J. Gerathewohl, Oskar L. Ritter, and Herbert D. Stallings, "Producing the Weightless State in Jet Aircraft," Report 57–143, Air Force School of Aviation Medicine, Aug. 1957.

[19] Gerathewohl, *Principles of Bioastronautics*, 211–234; Siegfried J. Gerathewohl and Herbert D. Stallings, "Experiments during Weightlessness: A Study of the Oculo-Agravic Illusion," *Journal of Aviation Medicine*, XXIX (July 1958), 504–515; Julian E. Ward, Willard R. Hawkins, and Herbert D. Stallings, "Physiologic Response to Subgravity I: Mechanics of Nourishment and Deglutition of Solids and Liquids," *Journal of Aviation Medicine*, XXX (March 1959), 151–154, and "Physiologic Response to Subgravity II: Initiation of Mictruition," *Aerospace Medicine*, XXX (Aug. 1959), 572–575.

[20] "They Float through the Air," *Astronautics*, IV (Feb. 1959), 42; Hanrahan and Bushnell, *Space Biology*, 147–148; William Leavitt, "The Weird World of Weightlessness," *Air Force*, XLII (April 1959), 113.

[21] Gerathewohl, "Weightlessness," 108–132. The Navy School of Aviation Medicine experiments also employed parabolic aircraft flights, while the Lewis studies featured use of a tall drop-tower.

[22] David G. Simons, "Review of Biological Effects of Subgravity and Weightlessness," *Jet Propulsion*, XXV (May 1955), 209–211; Fisher, "Aviation Medicine on the Threshold of Space," 257.

[23] Gerathewohl, "Weightlessness," 132. See also Oskar L. Ritter and Siegfried J. Gerathewohl, "The Concepts of Weight and Stress in Human Flight," paper no. 58–154, Air Force School of Aviation Medicine, June 26, 1958.

[24] Von Beckh, "Human Reactions during Flight to Acceleration Preceded by or Followed by Weightlessness," 391–406. After the termination of zero-g flights at Holloman and Randolph, weightless experiments in aircraft continued at Wright-Patterson and at the Air Force Flight Test Center, Edwards Air Force Base, Calif.

[25] See Mae M. Link and Hubert A. Coleman, *Medical Support of the Army Air Forces in World War II* (Washington, 1955).

[26] Hanrahan and Bushnell, *Space Biology*, 86–88; David Bushnell, "Major Achievements in Biodynamics: Escape Physiology at the Air Force Missile Development Center, 1953–1958," Air Force Missile Development Center, 1959, 10–13; Martin and Grace Caidin, *Aviation and Space Medicine* (New York, 1962), 199–203; Mallan, *Men, Rockets, and Space Rats*, 99–116. Stapp had taken his first rocket sled ride in 1947 at Edwards Air Force Base, Calif. He became Chief of the Aeromedical Field Laboratory in 1953 and made several more rides before his record run on Dec. 10, 1954. See John P. Stapp, "Tolerance to Abrupt Deceleration," in *Collected Papers on Aviation Medicine, Presented at Aeromedical Panel Meetings of the Advisory Group for Aeronautical Research and Development, North American Treaty Organization* (London, 1955), 122–169.

[27] Eli L. Beeding, Jr., and John D. Mosely, "Human Deceleration Tests," Air Force Missile Development Center, Jan. 1960; Hanrahan and Bushnell, *Space Biology*, 93–94. The "daisy track" was named for a popular make of air rifle, because it was originally designed as a compressed-air catapult system. From 1955 to 1959 it used a cartridge system.

[28] John P. Stapp, "Biodynamics of Space Flight," in Gantz, ed., *Man in Space*, 68.

[29] See William J. White, *A History of the Centrifuge in Aerospace Medicine* (Santa Monica, Calif., 1964).

[30] Gauer and Haber, "Man under Gravity-Free Conditions," 641–643.

[31] Hanrahan and Bushnell, *Space Biology*, 72.

[32] *Ibid.*, 75–76. The largest centrifuge in operation in the United States during the 1950s was the Navy's mechanical arm at Johnsonville, with a radius of 50 feet and a capability of 40 g. The Johnsville facility had a device allowing the gondola to be gimbaled to simulate buffetings and cross-currents. The Wright Air Development Center centrifuge, on the other hand, had a radius of 20 feet and a capability of 20 g. Instead of a gondola it featured an open platform, which could be whirled in one plane only.

[33] *Ibid.*, 77; John P. Stapp, "Acceleration: How Great a Problem?" *Astronautics*, IV (Feb. 1959), 38–39, 98–100.

[34] *Ibid.*, 77, 105–109; memo for files, Gerard J. Pesman, Human Factors Br., Space Task Group, "Present Status—Major Systems, Pilot Support and Restraint" [about Feb. 1959]; Harald J. von Beckh, "Multidirectional G-Protection in Space Vehicles," *Journal of the British Interplanetary Society*, XVI (Sept.–Oct. 1958), 531.

[35] Hanrahan and Bushnell, *Space Biology*, 96–98.

[36] Carl C. Clark and James D. Hardy, "Preparing Man for Space Flight," *Astronautics*, IV (Feb. 1959), 18–21, 88; Clark and R. Flanagan Gray, "A Discussion of Restraint and Protection of the Human Experiencing the Smooth and Oscillating Accelerations of Proposed Space Vehicles," U.S. Naval Air Development Center, Dec. 29, 1959, 26–46. During 1957–1958 scientists at the Wright Air Development Center also carried out water-immersion studies, using a coffin-like container. Peak accelerations on the limited Wright centrifuge were only about 16 g, but the durations of the acceleration patterns were longer.

[37] John P. Stapp, interview, San Antonio, April 24, 1964.

[38] Maxime A. Faget, interview, Houston, Jan. 3, 1964, and Aug. 24, 1964; Gerard J. Pesman, interview, Houston, March 17, 1964; James M. Grimwood, *Project Mercury: A Chronology*, NASA SP-4001 (Washington, 1963), 20. For USAF concept of rotating couch, see p. 96.

[39] Faget interview; Clark and Gray, "A Discussion of Restraint and Protection," 26; Pesman memo; John Dille, ed., *We Seven, by the Astronauts Themselves* (New York, 1962), 110–112.

[40] Clark and Gray, "A Discussion of Restraint and Protection," 26; Pesman memo. Faget and his men became even happier in December 1958, during the early days of Project Mercury, when a second Langley couch, its back angle raised 8 degrees, supported Lt. Carter C. Collins on the Navy centrifuge during a peak of 25 g for approximately 10 seconds.

[41] Stanley R. Mohler, "Wiley Post's Aerospace Achievements," *Airpower Historian*, XI (July 1964), 66–70; Frederick R. Ritzinger, Jr., and Ellis G. Aboud, "Pressure Suits—Their Evolution and Development," *Air University Review*, XVI (Jan.–Feb. 1965), 23–32.

[42] Caidin and Caidin, *Aviation and Space Medicine*, 49–54; Eugene M. Emme, *Aeronautics and Astronautics: An American Chronology of Science and Technology in the Exploration of Space, 1915–1960* (Washington, 1961), 26, 29, 30, 33, 160, 162; Auguste Piccard, *Between Earth and Sky*, trans. Claude Apcher (London, 1950), and *Earth, Sky, and Sea*, trans. Christina Stead (New York, 1956). For a useful survey of research in the physiology of high-altitude living, see *From the Mountains to the Moon: Some Historical Aspects of Survival at Great Heights* (undated microfilm, produced by Biomedical Laboratory, University of California at Los Angeles, NASA Historical Archives, Washington).

[43] Hubertus Strughold, "The U.S. Air Force Experimental Sealed Cabin," *Journal of Aviation Medicine*, XXVII (Feb. 1956), 50; Hanrahan and Bushnell, *Space Biology*, 24–26.

[44] Strughold, "Air Force Experimental Sealed Cabin," 50–51; Hans-Georg Clamann, interview, San Antonio, April 23, 1964.

[45] Strughold interview.

[46] "USAF School Simulates Living in Space," 49–55.

[47] Emme, *Aeronautics and Astronautics*, 81, 95; Strughold interview; George R. Steinkamp and Willard R. Hawkins, "Medical Experimentation in a Sealed Cabin Simulator," in Otis O. Benson and Hubertus Strughold, eds., *Physics and Medicine of the Atmosphere and Space* (New York, 1960), 370–376.

[48] George T. Hauty, "Human Performance in Space," in Gantz, ed., *Man in Space*, 84–108. Besides the aircraft weightless and sealed-cabin programs, the School of Aviation Medicine

carried on various other research activities in space medicine. As early as 1947 scientists at the school were studying the ecological conditions on other planets. From this and other research came Strughold's *The Green and Red Planet: A Physiological Study of the Possibility of Life on Mars* (Albuquerque, 1953). Throughout the 1950s and to the present the Department of Space Medicine at the school has done research on the atmospheric composition of other planets, photosynthesis as a means of air supply, and other subjects.

[49] Charles A. Berry, "The Environment of Space in Human Flight," *Aeronautical Engineering Review,* XVII (March 1958), 38; George E. Ruff, "Isolation," *Astronautics,* IV (Feb. 1959), 22–23, 110–111. After 1951 psychologists in several universities in the United States and Canada conducted sensory deprivation studies, laboratory experiments in which a subject was immersed in water in a blackened room and thus was deprived of his visual, auditory, and kinesthetic senses. The experiments indicated "a general loosening of the subject's ability to perceive reality and the weakening of the stable norms against which perception is evaluated." Later studies at the Navy Air Crew Equipment Laboratory in Philadelphia, the Air Force School of Medicine, and the Wright Air Development Center demonstrated, however, that stable, well-trained persons "can endure severe restrictions of their natural habitat for relatively long periods of time without significant degradation." Gerathewohl, *Principles of Bioastronautics,* 308, 311. See also D. Ewen Cameron et al., "Sensory Deprivation: Effects upon the Functioning Human in Space Systems," in Bernard E. Flaherty, ed., *Psychophysiological Aspects of Space Flight* (New York, 1961), 225–237.

[50] Among astronomers, astrophysicists, and space flight experts there is considerable variation in the uses and definitions of the terms "meteoroid," "meteorite," and "meteor." Throughout this study the authors have employed what is apparently standard NASA terminology: a meteoroid is a solid object larger that a molecule and smaller than an asteroid, moving in interplanetary space; a meteorite is such an object that reaches Earth's surface without completely vaporizing in the atmosphere; and a meteor is the light phenomenon resulting from a meteoroid's entrance into the atmosphere.

[51] Hanrahan and Bushnell, *Space Biology,* 31; George Grimminger, "Probability That a Meteorite Will Hit or Penetrate a Body Situated in the Vicinity of the Earth," *Journal of Applied Physics,* XIX (Oct. 1948), 947–956; Fred L. Whipple, "Meteoric Phenomena and Meteorites: The Conquest of Interplanetary Space," in White and Benson, eds., *Physics and Medicine of the Upper Atmosphere,* 137–170. On the meteoroid phenomenon see also Whipple, "Meteorite Material in Space," in Benson and Strughold, eds., *Physics and Medicine of the Atmosphere and Space.*

[52] Hanrahan and Bushnell, *Space Biology,* 31.

[53] A. B. Thompson, "Physiological and Psychological Considerations for Manned Space Flight," Report E9R–12349, Rev., Chance Vought Aircraft, Inc., Dallas, July 7, 1959, 115.

[54] On cosmic radiation see, for example, James A. Van Allen, "The Nature and Intensity of the Cosmic Radiation," in White and Benson, eds., *Physics and Medicine of the Upper Atmosphere,* 239–266; Joseph A. Connor, "Space Radiation Protection," NASA–MSC fact sheet No. 106; Hermann J. Schaeffer, "Appraisal of Cosmic-Ray Hazards in Extra-Atmospheric Flight," in Alperin, Stern, and Wooster, eds., *Vistas in Astronautics,* 291–298; Gerathewohl, *Principles of Bioastronautics,* 133–138; and C. Frederick Hansen, "The Characteristics of the Upper Atmosphere Pertaining to Hypervelocity Flight," *Jet Propulsion,* XXVII (Nov. 1957), 1155–1156.

[55] Emme, *Aeronautics and Astronautics,* 77, 82.

[56] On Unidentified Flying Objects see several works by Donald E. Keyhoe, especially *Flying Saucers in Outer Space* (New York, 1953); and Donald H. Menzel, *Flying Saucers* (Cambridge, Mass., 1953).

[57] Malcolm D. Ross, "A Consideration of the U.S. Navy Strato-Lab Balloon Program and Its Contributions to Manned Space Flight," in *Proceedings of the Second National Conference on the Peaceful Uses of Space, Seattle, Washington, May 8–10, 1962,* NASA SP–8 (Washington, 1962), 261.

[58] Gerathewohl, *Principles of Bioastronautics,* 475–476.

[59] David G. Simons, "The 1954 Aeromedical Field Laboratory Balloon Flights: Physiological and Radiobiological Aspects," *Journal of Aviation Medicine,* XXVII (Apr. 1956), 100–110; Simons interview; Bushnell, "Major

Achievements in Space Biology at the Air Force Missile Development Center," 2–12.

[60] David G. Simons, "Psychophysiological Aspects of Manhigh," *Astronautics,* IV (Feb. 1959), 32–33; Bushnell, "Major Achievements in Space Biology at the Air Force Missile Development Center," 27–34.

[61] David G. Simons, "Manhigh II," Technical Report 59–28, Air Force Missile Development Center, Holloman Air Force Base, N. Mex., June 1959; Simons, "Psychophysiological Aspects of Manhigh," 33, 62; Simons, "Observations in High-Altitude, Sealed-Cabin Balloon Flight," in Gantz, ed., *Man in Space,* 133–160; Simons et al., "Personal Experiences in Space Equivalent Flight," in Flaherty, ed., *Psychophysiological Aspects of Space Flight,* 39–41; Bushnell, "Major Achievements in Space Biology at the Air Force Missile Development Center," 34–41; Simons, "Space Medicine—the Human Body in Space," monograph No. 6, *Journal of the Franklin Institute Series,* Dec. 1958, 169–178; Simons interview. For a popularly written personal account of the *Manhigh II* flight see David G. Simons and Don Schanche, *Man High* (Garden City, N.Y., 1960).

[62] "Manhigh III: USAF Manned Balloon Flight into the Stratosphere," Tech. Report 60–16, April 1961; Simons, "Psychophysiological Aspects of Manhigh," 63; Simons et al., "Personal Experiences in Space Equivalent Flight," 41–43.

[63] Simons, "Observations in High-Altitude, Sealed-Cabin Balloon Flight," 146. See also Simons, "Manhigh Balloon Flights in Perspective," in *Proceedings of the Second National Conference on the Peaceful Uses of Space,* 243–248. Simons' record for a manned ascent stood until May 4, 1961, when Cdr. Malcolm Ross and Lt. Cdr. Victor G. Prather reached 113,740 feet in an Office of Naval Research *Strato-Lab High V* balloon, launched from the carrier *Antietam.* Prather was killed during helicopter recovery when he stood up in the "horse collar" sling and fell into the ocean.

[64] Simons, "Manhigh II," 272–294; Hanrahan and Bushnell, *Space Biology,* 171–172; Simons interview.

[65] Simons, "Observations in High-Altitude, Sealed-Cabin Balloon Flight," 137; Simons, interview. On Air Force solar flare observatories, see David Bushnell, "The Sacramento Peak Observatory, 1947–1962," Air Force Office of Aerospace Research, 1962.

[66] Gerathewohl, *Principles of Bioastronautics,* 136–138; Hanrahan and Bushnell, *Space Biology,* 180–187; Connor, "Space Radiation Protection"; James A. Van Allen, "On the Radiation Hazards of Space Flight," in Benson and Strughold, eds., *Physics and Medicine of the Atmosphere and Space,* 2–11; House Committee on Science and Astronautics, 86 Cong., 1 sess. (1959), *U.S. Aeronautics and Space Activities, Jan. 1 to Dec. 31, 1958: Message from the President of the United States,* 3, 4.

[67] Simons, "Space Medicine—the Human Body in Space," 162.

[68] Connor, "Space Radiation Protection"; Hanrahan and Bushnell, *Space Biology,* 179–180, 187–188.

[69] F. L. Van der Wal and W. D. Young, "Project MIA (Mouse-In-Able), Experiments on Physiological Response to Space Flight," *Jet Propulsion,* XXXI (Oct. 1959), 716–720; Ashton Graybiel, et al., "An Account of Experiments in Which Two Monkeys Were Recovered Unharmed after Ballistic Space Flight," *Aerospace Medicine,* XXX (Dec. 1959), 871–931; House Committee on Science and Astronautics, 86 Cong., 1 sess. (1959), *Jupiter Missile Shot—Biomedical Experiments, Hearings;* David S. Akens, *Historical Origins of the George C. Marshall Space Flight Center* (Huntsville, Ala., 1960), 52, 54–56; Gerathewohl, *Principles of Bioastronautics,* 98–108; Mae M. Link, *Space Medicine in Project Mercury,* NASA SP–4003 (Washington, 1965), 27–28.

## *Chapter III*

[1] See Derek J. de Solla Price, *Little Science, Big Science* (New York, 1963); and A. Hunter Dupree, *Science in the Federal Government: A History of Policies and Activities to 1940* (Cambridge, Mass., 1957), 1–2, 369–391.

[2] Quoted in Frank J. Malina, "Origins and First Decade of the Jet Propulsion Laboratory," in Eugene M. Emme, ed., *The History of Rocket Technology: Essays on Research, Development, and Utility* (Detroit, 1964), 52.

[3] *Thirty-Fourth Annual Report of the National Advisory Committee for Aeronautics—1948* (Washington, 1951), 37.

[4] Hugh L. Dryden, "NACA: What It's Doing and Where It's Going," *Missiles and Rockets,* I (Oct. 1956), 44–46; *Thirty-Fifth Annual Report of the NACA—1949* (Washington, 1951), 19; *Thirty-Sixth Annual Report*

*of the NACA—1950* (Washington, 1951), 33; *Thirty-Seventh Annual Report of the NACA—1951* (Washington, 1952), 26; *Thirty-Eighth Annual Report of the NACA—1952* (Washington, 1954), 38; *Thirty-Ninth Annual Report of the NACA—1953* (Washington, 1955), 30–31; Arthur S. Levine, "U.S. Aeronautical Research Policy, 1915–1958: A Study of the Major Policy Decisions of the National Advisory Committee for Aeronautics," unpublished Ph. D. dissertation, Columbia University, 1963, 111–112. NACA's contribution to the International Geophysical Year's Project Vanguard was limited to the calculation of optimum satellite trajectories.

[5] Hugh L. Dryden, "Fact Finding for Tomorrow's Planes," *National Geographic*, CIV (Dec. 1953), 772. Dryden, a distinguished physicist with the National Bureau of Standards and a member of NACA's Committee on Aerodynamics since the 1930s, became the Director of NACA in 1949. Despite the tremendous acceleration of the space program in the 1960s, Dryden's words were prophetic for himself if not for his generation. He died in December 1965, two months before the first major launch in the Apollo program.

[6] Minutes, NACA Committee on Aerodynamics, Wallops Island, Va., June 24, 1952, 19–21; memo, M. B. Ames, Jr., Acting Asst. Dir. for Research, to Langley Aeronautical Laboratory, "Research on Space Flight and Associated Problems," July 10, 1952; memo, John W. Crowley, Assoc. Dir. for Research, to Ames Aeronautical Laboratory, "Research on Space Flight and Associated Problems," Aug. 26, 1952; memo, Crowley to Langley Aeronautical Laboratory, "Research on Space Flight and Associated Problems," Aug. 31, 1952; minutes, NACA Executive Committee, Moffett Field, Calif., July 14, 1952, 15. NASA Historical Archives, Washington.

[7] Memo, Henry J. E. Reid, Dir., Langley Aeronautical Laboratory, to NACA, "Research on Space Flight and Associated Problems," Aug. 5, 1952; NACA Research Authorization A73L95, Sept. 8, 1952.

[8] Memo, Reid to NACA, "Meeting of Committee on Aerodynamics at Wallops Island on June 24, 1952." May 26, 1952.

[9] Memo, Smith J. DeFrance, Dir., Ames Aeronautical Laboratory, to NACA, "Report on Research of Interest to Committee on Aerodynamics," May 29, 1952.

[10] "NACA Views Concerning a New Research Airplane," NACA, Washington, Aug. 1954. On the development of nickel for use in aircraft construction see F. B. Howard-White, *Nickel: An Historical Review* (New York, 1963), 249–258.

[11] Wendell H. Stilwell, *X–15 Research Results* (Washington, 1965), 11–16; Kenneth S. Kleinknecht, "The Rocket Research Airplanes," in Emme, ed., *History of Rocket Technology*, 205–208; Editors, *Air University Quarterly Review*, "The Spiral Toward Space," in Kenneth F. Gantz, ed., *Man in Space: The United States Air Force Program for Developing the Spacecraft Crews* (New York, 1959), 208–210; Myron E. Gubitz, *Rocketship X–15* (New York, 1960); Jules Bergman, *Ninety Seconds to Space: The Story of X–15* (New York, 1960). The X–2 was the last rocket-powered research airplane that flew before the X–15 went into operation, although the fifties also saw flights of jet-propelled research craft like the X–3, nicknamed the "Flying Stiletto," the X–4, and the variable-sweep X–5, as well as the rocket-powered X–1B, used by NACA for reaction-control and heating studies. *X–15: Research at the Edge of Space*, NASA EP–9 (Washington, 1964), 9.

[12] Stilwell, *X–15 Research Results*, 17–31; Editors, *Air University Quarterly Review*, "Spiral Toward Space," 210–212; *X–15*, 11–15; Charles V. Eppley, *The Rocket Research Aircraft Program, 1946–1962* (Edwards Air Force Base, Calif., 1962), 25–30; Gubitz, *Rocketship X–15*, 61–74; John V. Becker, "The X–15 Project: Part I: Origins and Research Background," *Astronautics and Aeronautics*, II (Feb. 1964), 52–61.

[13] Memo, DeFrance to NACA, "Research on Space Flight and Associated Problems," Sept. 18, 1952.

[14] Mark Morton, "Progress in Reentry-Recovery Vehicle Development," pamphlet, Missile and Space Vehicle Dept., General Electric Co., Philadelphia, Jan. 2, 1961.

[15] Jacques Cattell, ed., *American Men of Science: A Biographical Directory: The Physical and Biological Sciences* (10 ed., Tempe, Ariz., 1960), 42; H. Julian Allen, biography sheet, NASA/Ames Research Center, Aug. 1963. Besides supporting the aeronautical laboratory at the California Institute of Technology, Guggenheim philanthropies also made possible the establishment of research institutions for aeronautics at Stanford and elsewhere.

[16] *Ibid.*, Alvin Seiff, "A Free-Flight Wind Tunnel for Aerodynamic Testing at Hypersonic Speeds," NACA Tech. Report 1222, *Forty-First Annual Report of the NACA—1955* (Wash-

ington, 1957), 381–398; Alvin Seiff and Thomas N. Canning, interviews, Moffett Field, Calif., April 22, 1964. The schlieren method was invented in the early 20th century by the Viennese physics professor and philosopher Ernst Mach, who also devised the unit of measurement representing the ratio of the speed of a body to the speed of sound in the surrounding air, i.e., mach 1. The schlieren technique involves training a beam of light perpendicular to the direction of the airflow to be investigated. A camera is placed behind the light. The camera then photographs a stationary or moving object in the light beam and the surrounding air-streaks, which have varying densities and refractive indices resulting from aerodynamic pressures. See Theodore von Kármán, *Aerodynamics: Selected Topics in the Light of Their Historical Development* (Ithaca, N.Y., 1954), 106–108; and Dr. W. Holder and R. S. North, "Optical Methods of Examining the Flow in High-Speed Wind Tunnels," Part I: "The Schlieren Method," North Atlantic Treaty Organization Advisory Group for Aeronautical Research and Development, Nov. 1956.

[17] H. Julian Allen, interview, Moffett Field, Calif., April 22, 1964.

[18] *Ibid.; Science News Letter,* LXXII (Dec. 21, 1957), 389.

[19] *Ibid.;* Allen C. Fisher, Jr., "Exploring Tomorrow with the Space Agency," *National Geographic,* CXVII (July 1960), 85; *Forty-Third Annual Report of the NACA—1957* (Washington, 1957), 5.

[20] H. Julian Allen and Alfred J. Eggers, Jr., "A Study of the Motion and Aerodynamic Heating of Ballistic Missiles Entering the Earth's Atmosphere at High Supersonic Speeds," NACA Tech. Report 1381, *Forty-Fourth Annual Report of the NACA—1958* (Washington, 1959), 1125–1140. Allen and Eggers pointed out that while the blunt shape was optimum for relatively lightweight reentry bodies, as warheads became heavier the total heat absorbed and the rate of heating would probably dictate longer, more slender shapes. Some blunting at the tip of the body, however, would continue to be desirable. This is precisely the evolution that has occurred over the years as rocket thrust has increased and warheads have grown heavier. See Herman H. Kurzweg, "Basic Research," in *Proceedings of the Second NASA-Industry Program Plans Conference,* NASA SP–29 (Washington, 1963), 127–130.

[21] Letters, H. H. Nininger to Ames Aeronautical Laboratory, Aug. 23, 1952; Daniel F. Wentz, Aeronautical Information Specialist, Ames, to Nininger, Sept. 18, 1952; Nininger to Wentz, Sept. 23, 1952; Nininger to Robert Nininger, July 5, 1957; Crowley to Nininger, July 12, 1957, in selected papers of H. H. Nininger 1935–1957, NASA Hist. Archives. Regarding Nininger's claims, Allen has commented: "It is rather ironical that Nininger's 'proof' that blunt bodies are optimum was based on observations of meteorites. All meteorites . . . enter the atmosphere in a speed range for which one can demonstrate that a body which is pointed at the stagnation point is the optimum and not the blunted body as proposed by Dr. Nininger." Letter, Allen to C.C.A., Aug. 17, 1964.

[22] *Forty-Fourth Annual Report,* 30. Doolittle, leader of the famous carrier-based raid of B–25s on Tokyo, succeeded Hunsaker as chairman of the NACA Main Committee in 1956.

[23] Richard V. Rhode, "Structures and Materials Aspect of Manned Flight Systems—Past and Present," NASA/MSC fact sheet, July 12, 1962.

[24] See, for example, David H. Crawford and William D. McCauley, "Investigation of the Laminar Aerodynamic Heat-Transfer Characteristics of the Hemisphere-Cylinder in the Langley 11-Inch Hypersonic Tunnel at a Mach Number of 6.8," NACA Tech. Report 1323, *Forty-Third Annual Report,* 1001 1021; and Jackson R. Stalder, "A Survey of Heat Transfer Problems Encountered by Hypersonic Aircraft," *Jet Propulsion,* XXVII (Nov. 1957), 1178–1184. Throughout the mid- and late fifties other laboratories also carried on research in reentry body configurations, especially the Jet Propulsion Laboratory at the California Institute of Technology, which did contract research for the Army. See Lester Lees, "Laminar Heat Transfer over Blunt-Nosed Bodies at Hypersonic Flight Speeds," *Jet Propulsion,* XXVI (April 1956), 259–269, and "Recent Developments in Hypersonic Flow," *Jet Propulsion,* XXVII (Nov. 1957), 1162–1178.

[25] Rhode, "Structures and Materials Aspects of Manned Flight Systems."

[26] Wernher von Braun, "The Redstone, Jupiter, and Juno," in Emme, ed., *History of Rocket Technology,* 110–111; John W. Bullard, "History of the Redstone Missile System," Hist. Div., Army Missile Command, Oct. 1965, 141–142; Frederick I. Ordway III and Ronald C. Wakeford, *International Missile and*

*Spacecraft Guide* (New York, 1960), 44–45, 53–54; House Committee on Government Operations, 86 Cong., 2 sess. (1959), House Report No. 1121, *Organization and Management of Missile Programs,* 108.

[27] General Electric Co., Missile and Space Vehicle Dept., *Reentry Vehicles—Man Made Meteors* (Philadelphia, undated).

[28] Von Braun, "Redstone, Jupiter, and Juno," 111; *Reentry Studies,* 2 vols., Vitro Corp. report No. 2331–25, Nov. 25, 1958. On the significance of the differing approaches to the reentry problem of the Air Force and the Army see *Organization and Management of Missile Programs,* 108–109. See also W. R. Lucas and J. E. Kingsbury, "The ABMA Reinforced Plastics Ablation Program," reprint from *Modern Plastics* (Oct. 1960).

[29] Message, John A. Powers, Public Affairs Officer, Space Task Group, to Eugene M. Emme, NASA Historian, July 5, 1960; *Forty-Third Annual Report,* 7; Leonard Roberts, "A Theoretical Study of Nose Ablation," and Aleck C. Bond, Bernard Rashis, and L. Ross Levin, "Experimental Nose Ablation," in "NACA Conference on High-Speed Aerodynamics, Ames Aeronautical Laboratory, Moffett Field, Calif., March 18, 19, and 20, 1958, A Compilation of the Papers Presented," 253–284.

[30] Paul E. Purser, log of administrative activities related to space and missile research, Jan. 4, 1956, to April 25, 1958. See also John R. Dawson, "Hydro-dynamic Characteristics of Missiles Launched Under Water," in "NACA Conference on High-Speed Aerodynamics," 177–184.

[31] Maxime A. Faget, interview, Houston, Jan. 9, 1964; Joseph A. Shortal, interview, Langley Field, Va., Jan. 7, 1964.

[32] Seiff and Canning interviews.

[33] Dr. Alfred J. Eggers, Jr., biography sheet, NASA/Ames Research Center, March 1963.

[34] Alfred J. Eggers, Jr., "A Method for Simulating the Atmospheric Entry of Long-Range Ballistic Missiles," NACA Tech. Report 1378, *Forty-Fourth Annual Report,* 1009–1015; *Forty-Third Annual Report,* 5.

[35] Eggers, "Method for Simulating the Atmospheric Entry of Long-Range Missiles," 1014; *Forty-Third Annual Report,* 6–7; Clarence V. Syvertson, interview, Moffett Field, Calif., April 22, 1964; letter, Eggers to C.C.A., June 24, 1964. For the kind of research done in the simulator, see Stanford E. Neice, "Preliminary Experimental Study of Entry Heating Using the Atmospheric Entry Simulator," in "NACA Conference on High-Speed Aerodynamics," 285–312.

[36] The critical problem of aerodynamic heating on the skip vehicle was not considered in the theoretical work on an antipodal bomber done by Eugen Sänger and Irene Bredt for the Luftwaffe in World War II. See Eugen Sänger, *Rocket Flight Engineering,* NASA TT F–223 (Washington, 1965).

[37] Alfred J. Eggers, Jr., H. Julian Allen, and Stanford E. Neice, "A Comparative Analysis of the Performance of Long-Range Hypervelocity Vehicles," NACA Tech. Report 1382, *Forty-Fourth Annual Report,* 1141–1160. A modified version of this paper is Allen, "Hypersonic Flight and the Reentry Problem," *Journal of the Aeronautical Sciences,* XXV (April 1958), 217–230.

[38] Alfred J. Eggers, "Performance of Long Range Hypervelocity Vehicles," *Jet Propulsion,* XXVII (Nov. 1957), 1147–1151. Actually the peak temperatures on the heatshield of the Mercury spacecraft during its reentry from an orbital mission reached approximately 3000 degrees F.

[39] Eggers' design is sometimes erroneously referred to as the "sled," after the nickname for a quite similar proposal first made in 1957 by Antonio Ferri and two others at the Gruen Applied Science Laboratories, of Hempstead, New York. See Antonio Ferri, Lewis Feldman, and Walter Daskin, "The Use of Lift for Re-entry from Satellite Trajectories," *Jet Propulsion,* XXVII (Nov. 1957), 1184–1191. Ferri, Feldman, and Daskin described a high-drag configuration which by flying at a proper angle of attack could produce a comparable amount of lift. Their vehicle would have an open top surface, and in this open area would be located a bubble-canopy sealed cabin. Reentry would be along a phugoid skip trajectory, with the lower surface of the vehicle acting as a heat sink.

[40] Purser log.

[41] Eggers letter; Syvertson interview.

[42] Memo, Major George D. Colchagoff to Lt. Col. R. C. Anderson, "New Research Systems," Feb. 16, 1956; Colchagoff interview, Washington, December 3, 1964; "Chronology of Early USAF Man-in-Space Activity, 1945–1958," Air Force Systems Command, 3–4.

[43] Colchagoff memo. Since 1952 the Air Force had sponsored studies of the rocket-launched glider concept at the Bell Aircraft Corp. (Project Bomi). These studies had been instigated at Bell by Walter Dornberger.

who was intrigued by the antipodal rocket bomber proposed during the war in Germany by Sänger and Bredt. See Sänger, *Rocket Flight Engineering.*

[44] Letter, David Bushnell to J. M. G., Dec. 11, 1964; Colchagoff interview; "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 4–5.

[45] "Chronology of Early Air Force Man-in-Space Activity, 1955–1960," Air Force Systems Command, 1.

[46] House Select Committee on Astronautics and Space Exploration, 85 Cong., 2 sess. (1958), *Astronautics and Space Exploration, Hearings,* testimony of Arthur Kantrowitz, 509.

[47] "Chronology of Early Air Force Man-in-Space Activity, 1955–1960," 2–6; Mae M. Link, *Space Medicine in Project Mercury,* NASA SP–4003 (Washington, 1965), 23–24; "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 6. The Western Development Division was renamed the Ballistic Missile Division on June 1, 1957.

[48] Minutes, NACA Executive Committee, Washington, Feb. 21, 1957, 7–8, NASA Hist. Archives.

[49] "Preliminary Investigation of a New Research Airplane for Exploring the Problems of Efficient Hypersonic Flight," NACA/Ames Aeronautical Laboratory, Moffett Field, Calif., Jan. 18, 1957. This Ames proposal for a hypervelocity glider with a round bottom for heat protection should not be confused with Eggers' M–1 concept, which was planned as a much smaller manned satellite vehicle. The technical kinship between the two, however, is obvious.

[50] Letter, Hartley A. Soulé to J. M. G., Aug. 29, 1965.

[51] Letter, Crowley to Edward W. Sharp, Dir., Lewis, June 17, 1957; letter, Crowley to Reid, Langley, June 17, 1957; memo, Crowley to Ames, "Meeting of Round III Steering Committee to be held at NACA Headquarters, July 2, 1957," June 18, 1957; memo for Dir., Clotaire Wood, "Presentation to Air Force Headquarters on Round III," July 11, 1957; "Study of the Feasibility of a Hypersonic Research Airplane," NACA, Washington, Sept. 8, 1957.

[52] *Ibid.*, 6–24. The term "Round Three," as used by the NACA and Air Force, referred to the third phase of the research airplane program, the first beginning with the X–1 and extending through the X–2, the second being the X–15.

[53] Eggers letter; Paul Purser, interview, Houston, Feb. 12, 1964; Faget, interview, Aug. 24, 1964.

[54] Hartley Soulé recalled that during the Round Three Conference, Faget asked for the floor and declared that NACA had misplaced its research emphasis, that he would spend no more effort on the Round Three concept, and that henceforth he would go to work on orbiting a man as fast as possible. "For me," said Soulé, "Project Mercury was born with Faget's remarks. . . ." Soulé letter.

[55] This was a phrase current in ARDC in 1956–1957, Colchagoff interview; Virgil I. Grissom, interview, Houston, April 12, 1965.

[56] *Astronautics and Space Exploration,* testimony of Kantrowitz, 510; "Chronology of Early Air Force Man-in-Space Activity, 1955–1960," 14–15; "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 8.

[57] *Ibid.;* Link, *Space Medicine in Project Mercury,* 24.

[58] Chronology of Early Air Force Man-in-Space Activity, 1955–1960," 15; House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), House Report No. 67, *A Chronology of Missile and Astronautic Events,* 36; *New York Times,* Dec. 11, 14, 1957.

[59] "Chronology of Early Air Force Man-in-Space Activity, 1955–1960," 12, 18–19.

[60] Letter, Donald L. Putt, Deputy Chief of Staff, Development, United States Air Force, to Dryden, Director, NACA, Jan. 31, 1958.

[61] Memorandum of Understanding, "Principles for Participation of NACA in Development and Testing of the Air Force System 464L Hypersonic Boost Glide Vehicle (Dyna-Soar I)," May 20, 1958, NASA Hist. Archives. In July 1958 the Air Force awarded concurrent feasibility study contracts to two contractor teams headed by the Martin Company and the Boeing Company. Almost two years later, after Project Mercury was well underway, Martin was chosen to build the booster system and Boeing the hypersonic vehicle itself. By that time the Dyna-Soar concept called for a true satellite vehicle acting as a controllable glider in the atmosphere. After a complex and controversial history, Dyna-Soar finally fell victim to leapfrogging space technology, particularly the two-man Gemini program initiated by NASA. Economy drives in the Defense Department also played a part in this December 10, 1963, decision. After an expenditure of over $350 million without a single test flight, and in the face of a predicted total cost of around $800 million, Secretary of Defense Robert S. McNamara ordered the can-

cellation of the Dyna-Soar project. On the general characteristics of Dyna-Soar see, for example, Senate Committee on Aeronautical and Space Sciences, 87 Cong., 2 sess. (1962), *Manned Space Flight Program of the National Aeronautics and Space Administration: Projects Mercury, Gemini, and Apollo,* 151–154; Glenn L. Martin Co. advertisement, *Space/Aeronautics,* XXX (Dec. 1958), 78; "Dyna-Soar's History Full of Re-examinations," *Aviation Week,* LXXVII (July 22, 1963), 233; and Martin Caidin, *Rendezvous in Space* (New York, 1962), 260–269.

[62] "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 13; House Committee on Science and Astronautics, 86 Cong., 1 sess. (1960), *Project Mercury, First Interim Report,* 3.

## *Chapter IV*

[1] Minutes, NACA Committee on Aerodynamics, *Forrestal,* Nov. 18–20, 1957, 17–18.

[2] Minutes, NACA Executive Committee, Washington, Nov. 21, 1957, 6–5, NASA Hist. Archives, Washington. Jerome C. Hunsaker, who only the previous year had resigned the chairmanship of the Main Committee, initially was offered the chairmanship of the Special Committee on Space Technology, but he declined.

[3] Minutes, NACA Executive Committee, Washington, Feb. 20, 1958, NASA Hist. Archives.

[4] Hugh L. Dryden, interview, Washington, Aug. 31, 1965; Paul G. Dembling, interview, Washington, Sept. 2, 1965.

[5] Minutes, NACA Executive Committee, Washington, Jan. 16, 1958, NASA Hist. Archives; Arthur S. Levine, "United States Aeronautical Research Policy, 1915–1958: A Study of the Major Policy Decisions of the National Advisory Committee for Aeronautics," unpublished Ph. D. dissertation, Columbia University, 1963, 146–147.

[6] The speech was published in somewhat revised form as "Space Technology and the NACA," *Aeronautical Engineering Review,* XVII (March 1958), 32–34, 44. See also Jay Holmes, *America on the Moon: The Enterprise of the Sixties* (Philadelphia, 1962), 72.

[7] NACA Lewis Staff, "A Program for Expansion of NACA Research in Space Flight Technology, with Estimates of the Staff and Facilities Required," Washington, Feb. 10, 1958.

[8] See *Historical Sketch of NASA,* SP–29 (Washington, 1965), 5–9.

[9] "Chronology of Early USAF Man-in-Space Activity, 1945–1958," Air Force Systems Command, 11–12; "Chronology of Early Air Force Man-in-Space Activity, 1955–1960," Air Force Systems Command, 24.

[10] See n. 39, chap. III.

[11] Memo, Clarence A. Syvertson to Dir., Ames Aeronautical Laboratory, "Visit to WADC, Wright-Patterson AFB, Ohio, to Attend Conference on January 29–31, Concerning Research Problems Associated with Placing a Man in a Satellite Vehicle," Feb. 18, 1958. For a more detailed rundown of the company proposals presented at the conference, see James M. Grimwood, *Project Mercury: A Chronology,* NASA SP–4001 (Washington, 1963), 14–15.

[12] "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 13–15; "Chronology of Early Air Force Man-in-Space Activity, 1955–1960," 27–32.

[13] "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 16; George D. Colchagoff, interview, Washington, Dec. 3, 1964.

[14] See John B. Medaris, *Countdown for Decision* (New York, 1960); and David S. Akens, *Historical Origins of the George C. Marshall Space Flight Center* (Huntsville, Ala., 1960).

[15] House Committee on Science and Astronautics, 86 Cong., 1 sess. (1959), *U.S. Aeronautics and Space Activities, Jan. 1 to Dec. 31, 1958: Message from the President of the United States,* 8; Mary Stone Ambrose, "The National Space Program," unpublished M.A. thesis, 2 vols., American University, 1960–1961, I, 51–53; Levine, "U.S. Aeronautical Research Policy," 149–150.

[16] "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 16; "Chronology of Early Air Force Man-in-Space Activity, 1955–1960," 33–34. The first successful flight of the Atlas, as noted earlier, came on Dec. 17, 1957, when an Atlas-A, a test rocket minus the sustainer engine, impacted on its target about 500 miles downrange from Cape Canaveral. On Dec. 19, 1957, a Thor made its first fully guided flight with an all-inertial guidance system. See Julian Hartt, *The Mighty Thor: Missile in Readiness* (New York, 1961), 70–75.

[17] "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 17–18; memo, Lawrence A. Clousing to Dir., Ames Aeronautical Laboratory, "Working Conference for the Air Force 'Man-in-Space Soonest' Program, held March 10–11–12, 1958, at the Air Force

Ballistic Missile Division Offices, Los Angeles," March 24, 1958.

[18] *Ibid.*

[19] *Ibid.*

[20] *Ibid.*; John P. Stapp and David G. Simons, interviews, San Antonio, April 24, 1964.

[21] See Otto Gauer, "The Physiological Effect of Prolonged Weightlessness," in U.S. Air Force, *German Aviation Medicine, World War II* (2 vols., Washington, 1950), I, 577.

[22] Clousing memo; "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 11–12.

[23] *Ibid.*, "Chronology of Early Air Force Man-in-Space Activity, 1955–1960," 37–38; Clousing memo.

[24] See pp. 73–74.

[25] Memo, Ira H. Abbott, Asst. Dir. for Research, to Langley Aeronautical Laboratory, Ames Aeronautical Laboratory, Lewis Flight Propulsion Laboratory, and High Speed Flight Station, "Meeting of the Steering Committee for a New Research Vehicle," Feb. 19, 1958; memo, Hartley A. Soulé, "Meeting of the Steering Committee for a New Research Vehicle System at Ames Laboratory on March 11, 1958," March 12, 1958.

[26] Memo, John W. Crowley, Assoc. Dir. for Research, NACA, to Comdr., Air Research and Development Command, "Man-in-Space—NACA Participation in Preparing Abbreviated Development Plan," March 14, 1958; Proposed Memorandum of Understanding, "Principles for the Conduct by the NACA and the Air Force of a Joint Project for a Recoverable Manned Satellite Test Vehicle," April 11, 1958; memo, Clotaire Wood, Asst. Dir. for Research Management, to Dir. of Research and Development, Office of Deputy Chief of Staff, Development, Hq. USAF, "Transmittal of Copies of Proposed Memorandum of Understanding Between Air Force and NACA for Joint NACA-Air Force Project for a Recoverable Manned Satellite Test Vehicle," April 11, 1958; memo for files, Wood, "Tabling of Proposed Memorandum of Understanding Between Air Force and NACA for a Joint Project for a Recoverable Manned Satellite Test Vehicle," May 20, 1958. See also memo for historical files, Dryden, "The Signed Agreement of April 11, 1958, on a Recoverable Manned Satellite Test Vehicle," Sept. 8, 1965. The postponed joint NACA-Air Force manned satellite project should not be confused with the cooperative arrangement set up for Dyna-Soar, a formal agreement on which was signed by NACA and the Air Force in May 1958.

[27] Quoted in Senate Committee on Aeronautical and Space Sciences, 88 Cong., 1 sess. (1963), *Documents on International Aspects of the Exploration and Use of Outer Space, 1954–1962*, Staff Report No. 18, 52–53. See also Dwight D. Eisenhower, *The White House Years: Waging Peace, 1956–1961* (Garden City, N.Y., 1965).

[28] President's Scientific Advisory Committee, *Introduction to Outer Space*, in Senate Special Committee on Space and Astronautics, 85 Cong., 2 sess. (1958), *Compilation of Materials on Outer Space, No. 1*, 45–46. The foregoing account of the work of PSAC in the late winter of 1958 is taken mainly from interviews with Dryden, Wood, and Dembling, Washington, Aug. 31, Sept. 1 and 2, 1965; and memo, Dryden for Eugene M. Emme for NASA Historical Files, "The NACA–NASA Transition, October 1957 to October 1958," Sept. 8, 1965.

[29] Levine, "U.S. Aeronautical Research Policy," 151–156; Ambrose, "National Space Program," I, 79–87; Robert L. Rosholt, *An Administrative History of NASA, 1958–1963*, NASA SP-4101 (Washington, 1966), 6–12; Dryden interview. Eisenhower's message of April 2 is reprinted, among many other places, in House Select Committee on Astronautics and Space Exploration, 85 Cong., 2 sess. (1958), *Astronautics and Space Exploration, Hearings*, 820–821.

[30] The administration bill is reprinted, among other places, in *Astronautics and Space Exploration*, 11–15. The legislative history of the bill is discussed in detail in Alison E. Griffith, *The National Aeronautics and Space Act: A Study of Public Policy* (Washington, 1962).

[31] Indicative of the widespread and growing concern at Langley over the prospect of space flight was a special course in basic space technology, given by members of the Flight Research Division from Feb. to May 1958. The lectures covered such subjects as lunar orbits, rocket operation, aerodynamic heating of spacecraft, and the medical problems of space flight. See "Notes on Space Technology Compiled by the Flight Research Division," Langley Aeronautical Laboratory, Feb.–May 1958. One of the members of the Flight Research Division at the time has referred to these collected lectures as "essentially the first U.S. textbook in space flight technology." John P. Mayer, comments, Sept. 8, 1965.

[32] This estimate was broken down into 30 percent space research in aerodynamics, 20 percent in propulsion, and 5 percent in structures.

Minutes, NACA Committee on Aerodynamics, Moffett Field, Calif., March 21, 1958, 6.

[33] "National Advisory Committee for Aeronautics, Organization and Distribution of Effort Related to Space Research for the Fiscal Year 1958," chart in *Astronautics and Space Exploration*, 404–405.

[34] These generalizations are based on conversations with various senior members of the technical staff at what is now the NASA Ames Research Center, Moffett Field, Calif., April 22–23, 1964. During this visit mottoes such as "NACA Forever" and "NASA Go Home" were observed posted around the laboratories.

[35] Paul E. Purser, interview, Houston, Feb. 12, 1964.

[36] See Ms., anon., "NACA Research into Space," Washington, Dec. 1957; and William M. Bland, Jr., "The Design of Multistage Rocket Vehicles for Hypersonic Research," Langley, 1958.

[37] For the characteristics of the Scout see "Considerations Affecting Satellite and Space Probe Research with Emphasis on the 'Scout' as a Launch Vehicle," NASA Tech. Report R-97, Washington, 1961.

[38] Maxime A. Faget, biography sheet, NASA/MSC, May 1963.

[39] Charles W. Mathews, interview, Houston, Feb. 24, 1964; Faget, interview, Houston, Aug. 24, 1964; Purser, log of administrative activities related to space and missile research, Jan. 4, 1956, to April 25, 1958.

[40] "NACA Conference on High-Speed Aerodynamics, Ames Aeronautical Laboratory, Moffett Field, Calif., March 18, 19, and 20, 1958: A Compilation of the Papers Presented."

[41] Maxime A. Faget, Benjamine J. Garland, and James J. Buglia, "Preliminary Studies of Manned Satellites—Wingless Configurations: Nonlifting," *ibid.*, 9–34.

[42] John V. Becker, "Preliminary Studies of Manned Satellites—Winged Configurations," *ibid.*, 45–58.

[43] Thomas J. Wong, Charles A. Hermach, John O. Reller, Jr., and Bruce E. Tinling, "Preliminary Studies of Manned Satellites—Wingless Configurations: Lifting Body," *ibid.*, 35–40.

[44] Letter, Alfred J. Eggers to C. C. A., June 24, 1964.

[45] Faget interview.

[46] For the specific problems in launching and recovering a manned satellite being examined at Langley, see the outline "Manned Satellite Program, Prepared by the NACA staff, March 12, 1958."

[47] Rosholt, *Administrative History of NASA*, 37–40; memo, Warren J. North to NASA Administrator, "Background of Project Mercury Schedules," with enclosures, Aug. 14, 1960.

[48] "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 19–20; "Chronology of Early Air Force Man-in-Space Activity, 1955–1960," 38–39. See pp. 81–82.

[49] "Chronology of Early Air Force Man-in-Space Activity, 1955–1960," 41, 43–44; "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 21–22. See also Mae M. Link, *Space Medicine in Project Mercury*, NASA SP-4003 (Washington, 1965), 25.

[50] "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 23.

[51] "Proposal for a Manned Satellite," Avco Manufacturing Corp., and Convair/Astronautics Div., General Dynamics Corp., April 30, 1958.

[52] "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 22–23; "Chronology of Early Air Force Man-in-Space Activity, 1955–1960," 45–46.

[53] Memo for files, Faget, "Attendance at ARDC Briefing on 'Man in Space' Program," March 5, 1958. See also memo to NACA, Soulé, "Second Discussion of ARDC Briefing on 'Man in Space' Program," March 27, 1958.

[54] "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 23–34; "Outline of History of USAF Man-in-Space Research and Development Program," Air Force information policy letter supplement No. 109, Aug., 1962, published in *Missiles and Rockets*, X (March 26, 1962), 148; memo, Crowley to Langley, Ames, Lewis Laboratories and High Speed Flight Station, "An AVCO-Convair Proposal for Manned Satellite," May 16, 1958.

[55] "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 25.

[56] See memo, Herbert F. York, Chief Scientist, ARPA, to Roy W. Johnson, "Next Steps to be Taken in Formulating Man in Space Program," June 7, 1958.

[57] "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 25–27; "Outline of History of USAF Man-in-Space Program," 148.

[58] Faget interview; memo, Faget to Dryden, "Faget Dealings with ARPA during the Past Several Weeks," June 5, 1958; York memo.

[59] "Outline of History of Man-in-Space Program," 149; "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 26;

"Chronology of Early Air Force Man-in-Space Activity, 1955–1960," 53–54.

[60] See "Current NACA Aerodynamic Research Relating to Upper Atmosphere and Space Technology," NACA Hq., March 10, 1958; "NACA Research into Space," 6–15; memo, Purser to Robert R. Gilruth, "Langley Manned Satellite Program," April 11, 1958.

[61] Purser interview.

[62] Purser log; Grimwood, *Mercury Chronology*, 14; William M. Bland, Jr., "Project Mercury," in Eugene M. Emme, ed., *The History of Rocket Technology: Essays on Research, Development, and Utility* (Detroit, 1964), 212.

[63] Purser log; Purser memo.

[64] "How the Mercury Capsule Design Evolved," *Aviation Week*, LXX (Sept. 21, 1959), 52–53; letter, Alan B. Kehlet to L.S.S., July 2, 1964; Faget interview.

[65] "How Mercury Capsule Design Evolved," 53–54; Christopher C. Kraft, Jr., "A Review of Knowledge Acquired from the First Manned Satellite Program," NASA/MSC fact sheet No. 206.

[66] William E. Stoney, Jr., "Aerodynamic Heating of Blunt Nose Shapes at Mach Numbers Up to 14," in "NACA Conference on High-Speed Aerodynamics, Ames Aeronautical Laboratory, Moffett Field, Calif., March 18, 19, and 20, 1958, A Compilation of the Papers Presented," 227–244; Stoney, interview, Houston, Feb. 13, 1964; Alvin Seiff and Thomas N. Canning, interviews, Moffett Field, Calif., April 22, 1964.

[67] Wood, interview, Washington, Sept. 1, 1965; memo, Wood, "Background on WADC Letter to NASA of October 22, 1958, Covering 'Ablation/Heat Sink Investigation—Manned Reentry,'" Nov. 7, 1958. The Air Force and NACA investigators completed their tests in October 1958. ARDC had conducted tests at the Chicago Midway Laboratories, while the NACA engineers had worked in the hot jet facilities at Langley. Both groups devoted most of their time to studies of ablation. Memo, Lester J. Charnock, Tech. Dir., Deputy Chief of Staff for Plans and Operations, to Comdr., Air Research and Development Command, "Ablation/Heat Sink Investigation—Manned Reentry," Oct. 21, 1958.

[68] Memo, George M. Low to NASA Administrator, "House Committee Staff Report on Project Mercury," Jan. 26, 1960; "How Mercury Capsule Design Evolved," 55; Willard S. Blanchard, interview, Langley Field, Va., Jan. 6, 1964; Bland, "Project Mercury," 215.

[69] Besides fear of excessive g on the abort-reentry flight profile, the Air Force was reluctant to use the bare Atlas because of its unproven nature and because it supposedly would place a capsule in a lower orbit than the Thor-fluorine rocket, necessitating more tracking stations to maintain constant voice contact with the human passenger.

[70] Stanley C. White, interview, San Antonio, Aug. 18, 1965.

[71] See pp. 43–46.

[72] Faget, marginal notes on "Outline of History of Man-in-Space Program."

[73] "Outline of History of Man-in-Space Program," 149.

[74] "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 28–29; "Chronology of Early USAF Man-in-Space Activity, 1955–1960," 58–60.

[75] Colchagoff interview; "Outline of History of Man-in-Space Program," 149; "Chronology of Early USAF Man-in-Space Activity, 1955–1960," 60–62; "Chronology of Early USAF Man-in-Space Activity, 1945–1958," 29–30. Some sense of the frustration felt by various Air Force leaders regarding man-in-space plans during this period can be gained from the biographical sketch on Brig. Gen. Don D. Flickinger in Shirley Thomas, *Men of Space* (6 vols., Philadelphia, 1960–1963), III, 77–79.

[76] Public Law 85–568, 85 Cong., 2 sess. (1958), H.R. 12575, *National Aeronautics and Space Act of 1958*, Sec. 203(a).

[77] Charles S. Sheldon II, interview, Washington, Sept. 2, 1965; Glen P. Wilson, interview, Washington, Sept. 2, 1965.

[78] Frank Gibney and George F. Feldman, *The Reluctant Space-Farers: A Study in the Discovery of Politics* (New York, 1965), 68.

[79] Rosholt, *Administrative History of NASA*, 13–15; Ambrose, "National Space Program," 1, 92–152; Levine, "U.S. Aeronautical Research Policy," 172–180. The Space Council consisted of the Secretaries of State and Defense, the Administrator of NASA, the Chairman of the Atomic Energy Commission, and the President.

[80] Senate Special Committee on Space and Astronautics, 85 Cong., 2 sess. (1958), *Nominations, Hearings on the Nomination of T. Keith Glennan and Hugh L. Dryden.*

[81] Rosholt, *Administrative History of NASA*, 40–42; memo for Dir., NACA, Ira H. Abbott, Ralph E. Cushman, Paul G. Dembling, Robert J. Lacklan, Ralph E. Ulmer, Clotaire Wood, "Submittal of Final Report of Ad Hoc Committee on NASA Organization based on the

National Aeronautics and Space Act of 1958," Aug. 12, 1958; memo for Dir., NACA, "Functions of Organizational Elements in NASA Headquarters," July 25, 1958.

[82] "Development Proposal for Project Adam," Army Ballistic Missile Agency, Redstone Arsenal, Ala., April 17, 1958. The Adam concept involved use of drag flaps to slow the nose cone's rate of descent and provide aerodynamic stability during reentry. At lower altitudes, parachutes would deploy to slow the capsule down still more. The development plan for Adam specified that several primate flights would precede the first manned shot. Unquestionably the most unusual technical aspect of Adam, and one that later produced considerable amusement among the engineers who directed Project Mercury, was the tank filled with water, into which the payload would be tossed by an automatic mechanism in case of booster malfunction on the launch pad.

[83] Message, John B. Medaris to August Schomburg, Chief of Ordnance, Dept. of the Army, Feb. 12, 1958; notes, "Project 'Man Very High' (MVH)," Feb. 17, 1958; message, J. A. Barclay to "Col. Coffin," Washington, "Proposed Project Adam," April 1958; Norman L. Baker, "Air Force Won't Support Project Adam," *Missiles and Rockets,* III (June 1958), 40–41; Link, *Space Medicine in Project Mercury*, 26–27.

[84] *Astronautics and Space Exploration,* testimony of Hugh Dryden and Arthur Kantrowitz, 117, 420, 516–517; Holmes, *America on the Moon*, 73–74. In August, Avco representatives presented a briefing to Brig. Gen. Homer A. Boushey, Director of Advanced Technology, Headquarters USAF. The Ballistic Missile Division still opposed the drag-brake device and advocated the Man-in-Space-Soonest approach. "Chronology of Early Air Force Man-in-Space Activity, 1955–1960," 66.

[85] Memo, Roy W. Johnson, ARPA Dir., to Secretary of the Army, "Project Adam," July 11, 1958; "Project Adam Chronology," Army Ballistic Missile Agency, undated; memo, Donald A. Quarles, Deputy Secretary of Defense, to Secretary of the Army, "Project Adam," Aug. 15, 1958; Link, *Space Medicine in Project Mercury*, 27.

[86] "MER II: Navy Manned Satellite Study, Summary," Convair Div., General Dynamics Corp., Dec. 1958; House Committee on Science and Astronautics, 86 Cong., 2 sess. (1960), *Project Mercury, First Interim Report,* 4.

[87] Memo, Hugh Dryden, NACA Dir., to James R. Killian, Jr., "Manned Satellite Program," July 18, 1958.

[88] "Chronology of Early Air Force Man-in-Space Activity, 1955–1960," 63.

[89] *Ibid.*, 68; "Chronology of USAF Man-in-Space Activity, 1945–1958," 31–32; "Outline of History of Man-in-Space Program," 149; Colchagoff interview.

[90] The pros and cons of the military's place in space have been debated almost incessantly since the immediate post-Sputnik days. For a treatment of the controversy, see, for example, Vernon Van Dyke, *Pride and Power: The Rationale of the Space Program* (Urbana, Ill., 1964). In retrospect, it seems proper to conclude that "the real issue within the Government was not whether to have a military or civilian space effort, but to create suitable arrangements for both." House Committee on Government Operations, 89 Cong., 1 sess. (1965), *Government Operations in Space,* Staff Report No. 445, 36.

[91] See memo for files, Hugh M. Henneberry, NACA Space Flight Office, "Briefing by General Electric Representatives on Studies Related to Man-in-Space Program," July 17, 1958; memo, Henneberry and G. C. Deutsch, to Assoc. Dir., "Discussions with Avco and Lockheed Representatives Concerning Materials for Thermal Protection of Satellite Reentry Vehicles, Washington, June 26–27, 1958," Sept. 8, 1958.

[92] "Specifications for a Manned Satellite Capsule," Langley Research Center, undated; C. C. Johnson, interview, Houston, Feb. 13, 1964; Mathews interview.

[93] Memo for files, Purser, "General Background Material on Project Mercury," March 23, 1959; *Project Mercury, First Interim Report,* 5.

[94] Purser, interview, July 18, 1965; North memo; Ms., William M. Bland, Jr., for Project Mercury Technical History Program, "The Birth of the Little Joe Booster," undated; Bland, interview, Houston, April 14, 1965.

[95] House Select Committee on Astronautics and Space Exploration, 85 Cong., 2 sess. (1958), *Authorizing Construction for the National Aeronautics and Space Administration, Hearings,* 17–18.

[96] Eugene M. Emme, *Aeronautics and Astronautics: An American Chronology of Science and Astronautics in the Exploration of Space, 1915–1960* (Washington, 1961), 101.

[97] Memo, Roy Johnson, ARPA Dir., to NASA Administrator, "Man-in-Space Pro-

gram," Sept. 18, 1958.

[98] *Project Mercury, First Interim Report*, 5; Gilruth, interview, Houston, March 18, 1964; minutes, Panel for Manned Space Flight, Warren J. North, secretary, Sept. 24 and 30, and Oct. 1, 1958.

[99] T. Keith Glennan, "Proclamation on Organization of the National Aeronautics and Space Administration," NASA General Directive No. 1, Sept. 25, 1958.

[100] Quoted in message to Langley Research Center, Sept. 25, 1958.

## *Chapter V*

[1] T. Keith Glennan, in a letter to C. C. A. dated Dec. 18, 1963, said he could not recall precisely either the dates or the happenings at the meetings during his first official week in office. But he added, "It seemed the natural course for me to accept the recommendations of the only people who knew very much about the matter and initiate the program as soon as NASA became an operating agency. In short, I do not recall that President Eisenhower actually assigned the manned space flight program to NASA—I guess I just accepted the tasks which we would have to undertake." See also Clotaire Wood, interview, Washington, D.C., Sept. 1, 1965, for witness to the words to proceed.

[2] *NASA First Semiannual Report to Congress, Oct. 1, 1958–Mar. 31, 1959* (Washington, 1959); "Historical Sketch of NASA," NASA EP-29 (Washington, 1965).

[3] Memo, Roy W. Johnson to NASA Administrator, "Man-in-Space Program," Sept. 18, 1958; House Select Committee on Astronautics and Space Exploration, 85 Cong., 2 sess. (1958), *Authorizing Construction for the National Aeronautics and Space Administration*, 17–21; Senate Committee on Appropriations, 85 Cong., 2 sess. (1958), *The Supplemental Appropriations Bill, 1959, Hearings*, 801–806.

[4] Minutes, Panel for Manned Space Flight, Appendix A, 1, Warren J. North, secretary, Sept. 24 and 30, and Oct. 1, 1958. For membership of the committee, see p. 106.

[5] See Paul E. Purser, "History," in Purser, Maxime A. Faget, and Norman F. Smith, eds., *Manned Spacecraft: Engineering Design and Operation* (New York, 1964), 6, 8. Cf. articles by William Leavitt in John F. Loosbrock, ed., *Space Weapons: A Handbook of Military Astronautics* (New York, 1959), 107, 177.

[6] Alfred J. Eggers' advocacy of a higher L/D vehicle is discussed on pp. 68–69.

[7] Minutes, "Panel for Manned Space Flight." The final report of the NACA Special Committee on Space Technology, chaired by H. Guyford Stever, was not published, but it did circulate as a 15-page endorsement by seven working groups generally favorable to these plans for manned space flight. See Ms. in NASA Hq. Hist. Archives, "Recommendations to the NASA Regarding a National Civil Space Program," No. VIII–C, Oct. 28, 1958.

[8] Abe Silverstein, interview, Cleveland, May 1, 1964. For details on the launching of NASA, see Robert L. Rosholt, *An Administrative History of NASA, 1958 to 1963* (Washington, 1966), Chap. 3. See also "Top Aides Named by Space Agency," *New York Times*, Oct. 5, 1958.

[9] "Background Information on Langley Research Center," Public Affairs Office, LRC, June 1960. The bulk of the professional staff consisted of "aeronautical research engineers." Since about 1954 some engineers, recruited from industry or from "accredited" schools of aeronautics, together with senior and most valuable members of the NACA laboratory teams, had been given more nearly competitive salaries and the title of "aeronautical research scientist." College accreditation and comparative evaluation were as problematical in this as in any other field, but institutions with high reputations for excellence in aeronautical engineering and aerodynamics included the California and Massachusetts Institutes of Technology, Stanford, Michigan State, and Cornell Universities, and many others certified by various professional societies.

[10] A few generalizations may be hazarded about Langley before 1959. Most of its professional staff came from the South and Midwest; few had been academically trained as aeronautical engineers; most held only bachelor's degrees, usually in mechanical or electrical engineering, often from Georgia Institute of Technology, Virginia Polytechnic Institute, or Auburn University. An esprit de corps based on many years of valuable service to aviation and to the nation seems to have been pervasive. And certainly the Langley professional people always would insist on their own experience and contributions as having proved the artificiality of invidious distinctions between science and engineering. Most helpful for understanding the nature of governmental management of applied science is David Novick, "What Do We Mean By Research and Development?" in *California*

*Management Review* (Spring 1960), 21, as quoted in Merton J. Peck and Frederick M. Scherer, *The Weapons Acquisition Process: An Economic Analysis* (Boston, 1962), 27, 28.

[11] Hugh L. Dryden, interview, Washington, Aug. 31, 1965; Robert R. Gilruth, interview, Houston, March 18, 1964.

[12] See the biography by Frank Waters, *Robert Gilruth: Engineering Space Exploration* (Chicago, 1963), 24–60.

[13] Memo, Gilruth to Assoc. Dir., "Space Task Group," Nov. 3, 1958; memo to all concerned, Floyd L. Thompson, "Space Task Group," Nov. 5, 1958. See memos, Charles H. Zimmerman to Procurement Officer, "Request for Authority to Negotiate a Contract for Manned Satellite Capsules," Nov. 3, 1958; Sherwood L. Butler to NASA Hq., "Request for Authority," Nov. 4, 1958.

[14] Ms. notes, Jerome B. Hammack, "Manned Ballistic Satellite Group," Aug. 19, 1958; letter, Purser to Mary S. Ambrose, undated, 2; Andre J. Meyer, Jr., interview, Houston, Feb. 24, 1964. For key management positions and progression, see James M. Grimwood, *Project Mercury: A Chronology*, NASA SP–4001 (Washington, 1963), Appendix 8.

[15] Alfred Rosenthal, *The Early Years: Goddard Space Flight Center Historical Origins and Activities through December 1962* (Washington, 1964), 17–20, 27.

[16] Besides those named in the text, the original list of Space Task Group members on Nov. 5, 1958, included Edison M. Fields, Claiborne R. Hicks, Jr., Ronald Kolenkiewicz, John B. Lee, Herbert G. Patterson, Frank C. Robert, William C. Muhly, and Paul D. Taylor, as professionals; Shirley J. Hatley, Norma L. Livesay, Nancy C. Lowe, Betsy F. Magin, Joseph J. Rollins, Ronelda F. Sartor, Jacquelyn B. Stearn, Julia R. Watkins, and Shirley P. Watkins, as clerical staff. The 10 members of the formal Lewis detachment were Elmer H. Buller, A. M. Busch, W. R. Dennis, M. J. Krasnican, Glynn S. Lunney, Andre J. Meyer, W. R. Meyer, W. J. Nesbitt, Gerard J. Pesman, and Leonard Rabb. Others from Lewis, like John H. Disher and Kenneth C. Weston, also commuted informally.

[17] George M. Low, interview, Houston, March 19, 1964; Gilruth, interview; Dryden, interviews, Washington, Sept. 11, 1964, and Aug. 31, 1965.

[18] John P. Mayer, interview, Houston, Oct. 19, 1964. For an overview of scientific expectation from the IGY, see D. R. Bates, ed., *The Earth and Its Atmosphere* (New York, 1957; Science Editions, Inc., 1961), 97–112. The difference between "sounding" and "probe" rocket flights was generally accepted by 1958 as being a matter of altitude, with the division point at a height of one Earth radius. Sounding rockets were those ascending to about 3900 miles; instrumented rockets going higher than that were called probes. On the word "aerospace" as used by the Air Force, see David Burnham, "The Air Force Coins a Word," *The Reporter*, XXVIII (June 6, 1963), 32–33.

[19] On the evolution of the standard atmosphere, see the works of Harry Wexler, Director of Meteorological Research of the United States Weather Bureau, and the foreword by Maurice Dubin, Norman Sissenwine, and Wexler to *U.S. Standard Atmosphere, 1962* (Washington, 1962), xiv–xv. Also a 1957 course of lectures sponsored by Space Technology Laboratories and the University of California at Los Angeles provided a comprehensive topical guide to the "state-of-the-art" of aerospace technology and achieved wider circulation when printed: Howard Seifert, ed., *Space Technology* (New York, 1959).

[20] Peck and Scherer, *The Weapons Acquisition Process*, 9, passim. See also article by H. Guyford Stever, "Outer Space: The Technical Prospects" in Lincoln P. Bloomfield, ed., *Outer Space: Prospects for Man and Society* (Englewood Cliffs, N.J., 1962). Comments by Manley J. Hood of Ames, Oct. 29, 1965, disagree with this general assessment, but the missile divisions of old aircraft corporations were more often than not semi-autonomous.

[21] *NASA First Semiannual Report to Congress*, 36, 37, 50. On this synthesis, see Hugh L. Dryden, "Scientific Bases of Airplane, Projectile and Missile Development," paper, American Ordnance Assn., New York City, Dec. 7, 1955, 2–3. Cf. John B. Rae, "Science and Engineering in the History of Aviation," *Technology and Culture*, II (Fall 1961), 391–399.

[22] The Convair/Astronautics-Avco Mfg. Corp. "Proposal for a Manned Satellite," No. ARL 03752, April 30, 1958, was an excellent introduction for STG to the men behind the Atlas as well as to their preliminary thinking. Cf. "Study for Manned Space Vehicle," Convair/ Astronautics, June 1958; and H. S. Gault and M. R. Tyson, "Study—Increased Capability of XSM–65 for Manned Space Flight Using 'Off-the-Shelf' Upper Stages," Convair/Astronautics, A2P–059, Nov. 5, 1958. Memo, Silverstein to Assoc. Dir., Lewis Research Center, "Request for Information on Atlas LOX Pump Performance," Nov. 14, 1958; Silverstein interview.

[23] Ms., R. B. Oakley, "History of North American Aviation, Inc.," undated [about June 1964], 9. For some insight into General Electric's contribution to the NAA/GE studies, see memo for files, Hugh M. Henneberry, "Briefing by General Electric Representatives on Studies Related to Man-in-Space Program," July 17, 1958.

[24] James S. McDonnell, Jr., "The Conquest of Space: A Creative Substitute for War," speech, Washington University, St. Louis, June 9, 1958. Cf. McDonnell, "The Challenge of Man's Future in the Golden Age of Engineers," speech, University of Missouri School of Mines and Metallurgy, Rolla, Mo., May 26, 1957.

[25] "Manned Orbital Flight," Report 6272, McDonnell Aircraft Corp., Oct. 10, 1958. Cf. "Manned Orbital Flight Planning Proposal," Report 6418, McDonnell Aircraft Corp., Oct. 15, 1958. Kendall Perkins, interview, St. Louis, Aug. 31, 1964; Raymond A. Pepping, interview, St. Louis, Sept. 1, 1964.

[26] "Briefing for Prospective Bidders for Manned Satellite Capsule," STG, Nov. 7, 1958; Ms., Jack A. Kinzler for Project Mercury Technical History Program, "Manufacturing by NASA for Project Mercury," Aug. 1963; E. M. Gregory, interview, Langley Field, Va., Jan. 7, 1964; Caldwell C. Johnson, "Specifications for a Manned Satellite Capsule," undated [about Oct. 20, 1958]; C. C. Johnson, interview, Houston, Feb. 13, 1964.

[27] Faget, marginal notes on "Outline of History of United States Air Force Man-in-Space Research and Development Program," anon., Aug. 1962; Wood, "Comments on Draft of Congress Staff Report on Mercury," Jan. 26, 1960. See also Mae M. Link, *Space Medicine in Project Mercury* (NASA SP–4003, 1965), 16, 67.

[28] Purser, "Project Mercury Background Material," March 23, 1959, 1; Purser, "Summary of Management, Design and Operational Philosophy," lecture, University of Houston, Spring 1963, 3. Cf. Purser, Faget, and Smith, eds., *Manned Spacecraft*, 492.

[29] Link, *Space Medicine in Project Mercury*, 28. One of the best broad assessments of the "state-of-the-art" of aerospace technology at this time was prepared by the Rand Corporation under the direction of Robert W. Buchheim, and reissued as a Congressional report: House Select Committee on Astronautics and Space Exploration, 86 Cong., 1 sess. (1959), *Space Handbook: Astronautics and its Implications*, 105, 166.

[30] "Questions and Answers from Bidders' Briefing for Manned Space Satellite," STG, Nov. 7, 1959, 3; George F. MacDougall, Jr., interview, Houston, Sept. 13, 1965.

[31] "Specifications for Manned Space Capsule," specification No. S–6, Nov. 14, 1958, passim.

[32] See letter, Boone T. Guyton, sales manager, Missile and Space Systems Div., United Aircraft Corp., to Henry J. E. Reid, Dir., Langley Research Center, Nov. 26, 1958; Ruben F. Mettler, Space Technology Laboratories, to Gilruth, Nov. 11, 1958. After the bidders' briefing, STG mailed additional material to prospective bidders. See letters, Gilruth to all bidders on prime contract for Mercury capsule, Nov. 25, 1958. Cf. letters, Reid to prospective bidders on Mercury capsule, Nov. 19, 1958. Back in the fall of 1954, the X–15 research airplane attracted nine companies to attend the bidders' briefing, and only four submitted bids. Walter C. Williams, interview, Houston, Aug. 23, 1965.

[33] Memo for files, Charles J. Donlan, "Procedures for Technical Assessment of Manufacturers' Proposal . . . on Specification S–6," Dec. 10, 1958; memo, Silverstein to NASA Administrator, "Schedule for Evaluation and Contractual Negotiations for Manned Satellite Capsule," Dec. 24, 1958. See p. 137. MacDougall, interview; memo, Low to NASA Administrator, "Status of Manned Satellite Project," Nov. 25, 1958. See also letter, Clarence A. Syvertson, Ames Aeronautical Laboratory, to Dir., Langley Aeronautical Laboatory, re conference at Wright-Patterson Air Force Base, Jan. 29–31, 1958, on research problems associated with orbiting a manned satellite, Feb. 18, 1958.

[34] See John W. Bullard, *History of the Redstone Missile System*, U.S. Army Missile Command, Historical Monograph AMC 23–M, Redstone Arsenal, Alabama, Oct. 15, 1965; anonymous booklet, *This Is Redstone*, Chrysler Corporation Missile Division [Detroit, ca. Oct. 1958].

[35] Memos, Purser to Gilruth, "Procurement of Ballistic Missiles for Use as NASA Satellite Boosters," Sept. 25, 1958; "Procurement of Ballistic Missiles for Use as Boosters in NASA Research Leading to Manned Space Flight," Oct. 8, 1958. See also memo, Purser and Faget to Silverstein, "Assignment of Responsibility for ABMA Participation in NASA Manned Satellite Project," Nov. 12, 1958; A. Richard Felix, "Static Stability and Drag Investigation of Jupiter C Boosted NASA

Manned Space Capsule," ABMA Technical Note No. 76–58, Dec. 5, 1958.

[36] Messages, Ralph E. Cushman to Commanding General, Army Ordnance Missile Command, Jan. 8 and 16, 1959; memo, North to Asst. Dir. for Advanced Technology, "Visit to ABMA Regarding Boosters," Dec. 4, 1958. See also "Development and Funding Plans for AOMC Support of NASA Manned Satellite Project," AOMC, Dec. 12, 1958; and Faget, interview, Houston, Aug. 23, 1965.

[37] Memo, North to NASA Administrator, "Background of Project Mercury Schedules," Aug. 14, 1960; Ms., William M. Bland, Jr., for Project Mercury Technical History Program, "The Birth of Little Joe Booster," undated; Bland, interview, Houston, April 14, 1965. Unknown to STG, a JATO-powered ship-to-air missile named "Little Joe" had been authorized at the end of World War II to combat the Japanese suicide rocket or Baka bomb. See Eugene M. Emme, *Aeronautics and Astronautics: An American Chronology of Science and Technology in the Exploration of Space, 1915–1960* (Washington, 1961), 50.

[38] See the description by Bland, "Project Mercury," in Eugene M. Emme, ed., *The History of Rocket Technology: Essays on Research, Development and Utility* (Detroit, 1964), 224–226.

[39] Memo, Carl A. Sandahl to Assoc. Dir., Langley Research Center, "Langley Participation in Little Joe Project," Dec. 9, 1958.

[40] Letter, Donlan to J. A. O. Stankevics, Avco-Everett Research Laboratory, May 5, 1960.

[41] See John L. Chapman, *Atlas: The Story of a Missile* (New York, 1960), Chap. I and 154–165, for a description of Project Score. Low, "Status Report No. 1—Manned Satellite Project," Dec. 9, 1958. Johnson's concurrence on the manned satellite booster was reported in "Atlas Seen as Vehicle to Put Man Into Space," *Washington Post*, Dec. 22, 1958. See also, Frank J. Dore, comments, Aug. 16, 1965.

[42] Ms., Aleck C. Bond for Project Mercury Technical History Program, "Big Joe," June 27, 1963, 5. A large part of the President's first annual report, required by the Space Act of 1958, was devoted to the problems of reentry, including aerodynamic heating. See House Committee on Science and Astronautics, 86 Cong., 1 sess. (1959), *U.S. Aeronautics and Space Activities, Jan. 1 to Dec. 31, 1958: Message from the President of the United States*, 2, 12, 20, 23.

[43] Initial efforts to develop a reliable landing and recovery system for the Big Joe payloads were begun by STG in conjunction with Norfolk Navy Yard personnel in December 1958.

[44] Message, Commanding Officer, Wright Air Dev. Center, to C.O., Air Research and Development Command, July 9, 1958. On Army Ballistic Missile Agency's successes with ablative Jupiter nosecones in 1957 and 1958, see *Reentry Studies*, 2 vols., Vitro Corp. report no. 2331–25, Nov. 25, 1958; Sarah S. Whitaker, "Bibliography—Jupiter Nose Cones," MSFC, Sept. 14, 1962; and W. R. Lucas and J. E. Kingsbury, "The ABMA Reinforced Plastics Ablation Program," reprinted from *Modern Plastics* (Oct. 1960).

[45] Memo, Wood to Office of Space Flight Development, "Background on Letter of October 22, 1958, Covering 'Ablation/Heat Sink Investigation—Manned Reentry,'" Nov. 7, 1958. Cf. memo, Low to Newell Saunders, Nov. 28, 1958; "Specifications for Manned Space Capsule"; Faget (interview) said "Ablation was ruled out as a material in the competition for the simple reason that it would prove to be too much of a 'wild card' in the technical assessment." In other words, said George Low, Oct. 5, 1965, "we wanted to select the best spacecraft manufacturer and not only the best heat shield inventor."

[46] Jack C. Heberlig, interview, Houston, Feb. 20, 1964; Hammack, interview, Houston, Feb. 13, 1964. See pp. 50–52. For a convenient overview of the Manhigh, Excelsior, and Strato-Lab projects, see "Report on Manned Space Flight," session VII of *Proceedings of the Second National Conference on the Peaceful Uses of Space, Seattle, Washington, May 8–10, 1962*, NASA SP–8 (Washington, 1962), 241–261.

[47] "Project Mercury Status Report No. 1 for Period Ending Jan. 31, 1959," STG. See also, Emme, *Aeronautics and Astronautics 1915–1960*, appendix C, 161–165.

[48] Careful study of the "half proposal" by Winzen Research, Inc., described in "Technical Proposal for NASA Man-in-Space Capsule Program," No. 1160–P, Dec. 8, 1958, for a balloon-hoisted sealed cabin similar to those used in the Air Force Project Manhigh and the Navy Strato-Lab continued within STG for several more months and was instrumental in determining that this kind of "space soak" would not justify its cost.

[49] Low, "Status Report No. 2—Manned Satellite Project," Dec. 17, 1958. The danger

of friction was probably greatest in the anomalous relationship between the Advanced Research Projects Agency of the Department of Defense and the military services' own advanced research groups. Memorandum of understanding, NASA–ARPA Manned Satellite Panel, "Principles for the Conduct by NASA and the Department of Defense of a Joint Program for a Manned Orbital Vehicle," Sept. 19, 1958. See also memo, Gilruth for all concerned, "Organization of Space Task Group," Jan. 26, 1959.

[50] Letter, Silverstein to Lt. Gen. Roscoe E. Wilson, U.S. Air Force, Nov. 20, 1958; NASA-Army joint news release, "NASA-Army Agreement," Dec. 3, 1958; DeMarquis Wyatt, interview, Washington, Sept. 1, 1965.

[51] "Status Report No. 1." See also Link, *Space Medicine in Project Mercury*, 44–59.

[52] "Invitation to Apply for Position of Research Astronaut-Candidate," announcement No. 1, NASA Project A, Dec. 22, 1958, 1. Succeeding quotations are from pages 3 and 4. Original plans for a maximum age of 35 were compromised by the requirements for extensive experience. Accumulating 1500 hours of flying time requires about 10 years. See letter, Robert B. Voas to John A. Walter, Syracuse University, April 1, 1960.

[53] Low, "Status Report No. 3—Project Mercury," Dec. 27, 1958; letter, Emme to Link and Grimwood, March 23, 1964.

[54] Donlan, interview, Langley Field, Va., Jan. 7, 1964. Cf. Neil A. Armstrong, "I Decided to Get Aboard," *Life*, CV (Sept. 27, 1963), 84.

[55] Low, "Status Report No. 6—Project Mercury," Feb. 3, 1959; see also Donlan, comments, Sept. 3, 1965.

[56] Letter, Reid to NACA Dir., July 29, 1958; memo, Low to Silverstein, Dec. 12, 1959.

[57] Letter, Low to Grimwood, Nov. 13, 1963; Theodore von Kármán, *Aerodynamics: Selected Topics in the Light of Their Historical Development* (Ithaca, N.Y., 1954), 189. The famous Renaissance sculpture by Giovanni da Bologna of Mercury poised on a zephyr's head, ready to spring into space, is an "image of energy" and the "accepted symbol of victorious speed," according to Kenneth Clark, *The Nude: A Study in Ideal Form* (New York, 1959), 282.

[58] Edith Hamilton, *Mythology* (New York, 1958), 33; Thomas Bulfinch, *Mythology*, abridgement by Edmund Fuller (New York, 1959), 18; Emme, *Aeronautics and Astronautics, 1915–1960*.

[59] The announcement of the code name for NASA's man-in-space program was reported in a two-page edition of the strikebound *New York Times* as an incidental part of the main story: "Big Rocket Engine for Space Flights Is Ordered by U.S.," *New York Times*, Dec. 18, 1958. See also, Ms., Louise Dick, "Public Statements on Manned Space Flight and Project Mercury," Aug. 12, 1960, 4.

## *Chapter VI*

[1] House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *A Chronology of Missile and Astronautic Events*, 64–66; Eugene M. Emme, *Aeronautics and Astronautics: An American Chronology of Science and Technology in the Exploration of Space 1915–1960* (Washington, 1961), 106, 143. Cf. House Committee on Science and Astronautics, 86 Cong., 1 sess. (1959), *The First Soviet Moon Rocket*. On technological chauvinism, see the congressional furor aroused by Lloyd Mallan, "The Big Red Lie," a series of articles in *True* (April, May, June, July, 1959), which alleged Soviet space claims, especially *Mechta*, to be the "biggest hoax in history." House Committee on Science and Astronautics, 86 Cong., 1 sess. (1959), *Soviet Space Technology, Hearings*.

[2] "Project Mercury Discussion," brochure for press tour of Langley Research Center, STG, July 7, 1959, 1; Maxime A. Faget and Robert O. Piland, "Mercury Capsule and Its Flight Systems," paper, Institute of the Aeronautical Sciences, New York City, Jan. 25, 1960, 1–2; Ms., Paul E. Purser, "Project Mercury Technical History," June 12, 1963, intro., 5–6; Faget and Walter C. Williams, interviews, Houston, Aug. 23, 1965.

[3] T. Keith Glennan, "The Task of Government," in Lincoln P. Bloomfield, ed., *Outer Space: Prospects for Man and Society* (Englewood Cliffs, N.J., 1962), 65. For more of the background on engine and booster priority assignments, see Senate Committee on Aeronautical and Space Sciences, 87 Cong., 2 sess. (1962), Staff Report, *Manned Space Flight Program of the National Aeronautics and Space Administration: Projects Mercury, Gemini, and Apollo*, 160–168.

[4] Letter, Hugh L. Dryden to Robert R. Gilruth, March 23, 1959; memo, Clotaire Wood to NASA Administrator, "Priority for Project Mercury," March 12, 1959, Table D.

[5] Memo, Christopher C. Kraft to Gilruth, "Operational Program Estimate for AFMTC," Dec. 4, 1958.

## FOOTNOTES

[6] Letter, Lloyd Harrison to Charles H. Zimmerman, March 10, 1959; letter, C. F. Picard to Zimmerman, March 23, 1959; memo for files, R. L. Barber, "NASA Contract NAS 5–59—Manned Satellite Capsules," April 10, 1959; Senate Committee on Aeronautical and Space Sciences, 86 Cong., 1 sess. (1959), *Governmental Organization for Space Activities*, 42–43. For a different interpretation of the facts surrounding the DX priority for Mercury, Saturn, and the F–1 engine, see House Committee on Science and Astronautics, 86 Cong., 2 sess. (1960), *Space, Missiles, and the Nation*, 10–12. For details on the birth of the F–1 engine and the Saturn booster, see *Saturn Illustrated Chronology, April 1957–June 1964*, Marshall Space Flight Center, Aug. 10, 1964, 1–16.

[7] Memos, George M. Low to J. W. Gannon, "Priority for Project Mercury," April 25, 1959; Low to House Committee on Science and Astronautics, "Urgency of Project Mercury," April 27, 1959; House Committee on Science and Astronautics, 86 Cong., 1 sess. (1960), *1961 NASA Authorization*, 348.

[8] Roy W. Johnson, quoted by John W. Finney, "Space Ship Model Tested in Flight," *New York Times*, March 27, 1959. On rivalry and confusion in Washington, see Drew Pearson, "Too Many Czars in Space Work," *Washington Post*, Feb. 9, 1959; William Hines, "Policies of Washington Blamed for Missile Lag," Washington *Evening Star*, Feb. 17, 1959. For part of the furor over Project Argus, see Walter Sullivan, et al., *New York Times*, March 19, 20, 22, 1959. See also "Roy W. Johnson, Early Builder of U.S. Space Program, Dies," *New York Times*, July 23, 1965.

[9] See "Questions and Answers from Bidders' Briefing for Manned Space Satellite," STG, Nov. 7, 1958, 3; letter, Sherwood L. Butler to R. E. Cushman, "Proposals on Requisition S–6—Manned Satellite Capsule," Dec. 12, 1958.

[10] Glennan, "Statement of the Administrator on the Selection of McDonnell Aircraft Corporation to Design and Construct a Manned Satellite Capsule for Project Mercury," typescript, undated.

[11] NASA Contract No. NAS 5–59, "Cost-Plus-A-Fixed-Fee Research and Development Contract for Designing and Furnishing Manned [sic] Satellite Capsule." This document is officially dated Feb. 13, 1959, the date on which it was approved by Glennan. For an elaborate 37-page report on the contract negotiations, see memo for files, Willis A. Simons and George F. MacDougall, Jr., "Procurement of Manned Satellite Capsule (Project Mercury) (Requisition S–6)," Feb. 9, 1959.

[12] News release, "McDonnell Aircraft's Role as Prime Contractor for the Mercury Spacecraft," McDonnell Aircraft Corp., April 1962.

[13] Ms., Stephen A. Armstrong for Project Mercury Technical History Program, "The History of Project Mercury Contracts," April 8, 1963; Armstrong, interview, Houston, June 4, 1964.

[14] *Manned Satellite Proposal*, Vol. I: *Management Proposal;* Vol. II: *Technical Proposal;* Vol. III: *Cost Proposal*, Report 6483, McDonnell Aircraft Corp., Dec. 4, 1958.

[15] Prepared by L. M. Parker and approved by John F. Yardley, E. M. Flesh, and Albert Utsch of McDonnell, "Project Mercury Capsule Detail Specification," Report 6603, was first issued on March 12, 1959, and revised on April 10 and July 15, 1959. By the latter date McDonnell model designation "133K" had been assigned the Mercury capsule, indicating 11 significant drawing changes so far. Cf. "Specifications for Manned Spacecraft Capsule," Specification No. S–6, item 2.2.1.1, STG/Langley Research Center, Nov. 14, 1958.

[16] Low, "Status Report No. 4—Project Mercury," Jan. 12, 1959. Evidence that the earlier NASA capsule design continued to compete with the McDonnell configuration is found in studies of drogue parachute effectiveness in stabilizing the capsule at subsonic speeds. See memo, James S. Bowman, "Transmittal of Project Mercury Data to the Space Task Group," June 3, 1959. The precise shape of the "coolie hat" blast shield was still debated in late 1960. See letter, Purser to Walter F. Burke, "Progress Report on pylon jettison rockets test at NASA," Sept. 21, 1960.

[17] Low, "Status Report No. 5," Jan. 20, 1959. Cf. Low, "Status Report No. 3," Dec. 27, 1958.

[18] "Status Report No. 5"; *Manned Satellite Proposal*, Vol. II: *Technical Proposal*, 10.

[19] Andre J. Meyer, Jr., interview, Houston, Feb. 24, 1964, and comments, Sept. 1, 1965; Ms., Meyer for Project Mercury Technical History Program, "Mercury Heat Shield History," June 1963, regards the beryllium alternative as only a secondary solution from the beginning.

[20] Edison M. Fields, interview, Houston, June 18, 1964; Aleck C. Bond, interview, Houston, March 13, 1964.

[21] Purser, log for Gilruth, Jan. 14, 1959. Cf. "Specifications for Manned Spacecraft

Capsule." Memos, Fields to Chief, Flight Systems Div., "Visit to B. F. Goodrich Concerning Ablation Heat Shield for HS–24," April 20, 1959; and "Visit to C.T.L. Concerning Ablation Heat Shields for HS–24," April 21, 1959. General Electric Co. (Missile and Space Vehicle Dept., Philadelphia) had found it necessary to subcontract the large-scale development of its design process to the B. F. Goodrich Co., Akron. Big Joe flew a Goodrich heatshield.

[22] "Specification for Ablation Heat Shield," STG Specification No. S–19–B, April 28, 1959, a five-page revision by Fields of Specification No. S–19A, March 2, 1959. See also "Beryllium in Project Mercury," brochure, Brush Beryllium Co., undated [about June 1959]. For the techniques of ablation shield manufacture, see "Development of Reinforced Plastic Materials and Fabrication Procedures for Reentry Protection Shield for Capsule, Project Mercury," Cincinnati Testing and Research Laboratory, Reports Nos. 1 and 2 (final), May 1 and July 1, 1959.

[23] "How Mercury Capsule Design Evolved," *Aviation Week*, LXX (Sept. 21, 1959), 57.

[24] "Project Mercury Status Report No. 1 for Period Ending Jan. 31, 1959," STG/Langley Research Center, 2, 26. See also Ms. paper, Marvin S. Hochberg, "Design and Fabrication of the Project Mercury Astronaut Couch," an undated and unnumbered McDonnell Aircraft Corp. report received by STG June 20, 1963.

[25] Low, "Status Report No. 9—Project Mercury," March 21, 1959, 6. On this chart MA–1 stood for the flight that later became known as Big Joe. Hence all flights in the Atlas series dropped in numerical sequence; MA–7 became MA–6, but remained the first planned manned orbital flight.

[26] "Status Report on Project Mercury Development Program as of March 1, 1959," Public Affairs Office, Langley Research Center.

[27] Low, "Status Report No. 9—Project Mercury," 2, 4; W. C. Moseley, Jr., interview, Houston, Sept. 21, 1965.

[28] Willard S. Blanchard and Sherwood Hoffman, interview, Langley Field, Va., Jan. 6, 1964. Cf. their formal papers on configuration studies published after 18 months' lead time as TN D–223, "Effects of Nose Cone Radii, Afterbody Section Deflections, and a Drogue Chute on Subsonic Motions of Manned-Satellite Models in Reentry Configuration," March 1960; and as TM X–351, "Full-Scale Flight Test of a Proposed Abort-Escape System for a Manned Space Capsule from Sea Level," Aug. 1960; also Blanchard and James R. Raper, TM X–422, "Full-Scale Flight Test from Sea Level of an Abort-Escape System for a Project Mercury Capsule." Blanchard's work with tow rockets and the first full-sized model of the Mercury configuration was publicized by *Aviation Week*, which featured his picture on the cover of its April 1959 issue. Alternative modifications of the escape rocket system were being tested by Herbert G. Patterson using ¼-scale boilerplate capsule-pylon systems in beach abort launches from Wallops Island.

[29] For a résumé of these activities at Langley, see memo, Carl A. Sandahl to Assoc. Dir., "Langley Presentation to the Space Task Group," May 19, 1959. Cf. memo, Abe Silverstein to Dir., Aeronautical and Space Research, "Langley and Ames Research Center Support for Project Mercury," March 6, 1959, with two enclosures. See also memo, Lloyd J. Fisher to Assoc. Dir., "Flotation Investigations in Support of Project Mercury," May 12, 1959.

[30] Albin O. Pearson, interview, Langley Field, Va., Jan. 7, 1964; memo, Pearson to Assoc. Dir., "Visit of NASA Personnel to Arnold Engineering Development Center, Tullahoma, Tenn.," March 5, 1959; memo, Moseley for files, "Summary of Project Mercury Wind Tunnel Program," Aug. 26, 1960. See also Marvin E. Hintz, *A Chronology of the Arnold Engineering Development Center*, Air Force Systems Command Historical Publication Series 62–101, June 30, 1963, 62.

[31] "Pilot Support System Development (Live Specimen Experiment)," Report 6875, McDonnell Aircraft Corp., June 1959. Cf. "Test Results Memorandum," McDonnell Aircraft Corp., June 9, 1959. John H. Glenn, interview, Houston, Aug. 3, 1964; memo, Wilbur E. Thompson to Chief, Flight Systems Div., "Status of Impact Test Program," June 9, 1959.

[32] Letter, Gilruth to Commanding Officer, Wright Air Development Center, March 26, 1959; Low, "Status Report No. 11," April 6, 1959. Cf. "Project Mercury Status Report No. 2 for Period Ending April 30, 1959," STG/Langley Research Center. On the history of parachute development for Mercury, see Joe W. Dodson, transcript of a taped discussion with Donald C. Cole, "Mercury Parachute History," September 1962.

[33] William C. Muhly, interview, Houston, Aug. 9, 1965; see also Muhly's draft Ms., "Planning and Scheduling," May 28, 1963, for the Mercury Technical History. Regarding STG's first plans for astronaut pickup, see STG, "Recovery Operations for Project Mercury," March 20, 1959.

[34] See Chapters IX and X, pp. 287 and 311 following. Lloyd Fisher of Langley worked on a torus landing bag for several months in 1959 before the honeycomb structures developed well enough to abandon the idea for a while. But reconsiderations of dry landing from an abort at the Cape or nearing Africa led Gerard Pesman, Faget, and Donlan to reinstate the pneumatic impact bag development late in 1960. Pesman, interview, Houston, Aug. 16, 1965.

[35] E. Nelson Hayes, "The Smithsonian's Satellite-Tracking Program: Its History and Organization," Parts I and II, Publications 4482 and 4574, respectively (Washington, 1962–1964), I, 318.

[36] Letter, J. W. Crowley to F. L. Thompson, "Request that LRC Assume Responsibility for Project Mercury Instrumentation Facilities," Feb. 20, 1959, with enclosure (Silverstein to Crowley, Feb. 16, 1959); Charles W. Mathews, interview, Houston, Sept. 23, 1965; and Low, comments, Oct. 5, 1965.

[37] Hartley A. Soulé, interview, Hampton, Va., Jan. 7, 1964. Soulé retired in 1962 to write histories of Langley and of the Mercury tracking network. Cf. memo, Soulé to Assoc. Dir., "Questions Concerning the Project Mercury Range . . .," April 13, 1959.

[38] G. Barry Graves, interview, Houston, Feb. 17, 1964. Cf. memo, Graves to Gilruth, "Progress on Range for Project Mercury . . . ," Feb. 13, 1959.

[39] Letter, Henry J. E. Reid to Silverstein, April 27, 1959, with enclosure (Soulé, "Tentative Plan for Operation of Range for Project Mercury"). Cf. earlier plans in letter, Reid to Crowley, March 9, 1959.

[40] "Project Mercury Crew Station Description," Report 6710, McDonnell Aircraft Corp., March 16, 1959; "Model 133 Mockup Review Pictures," Report 6732, McDonnell Aircraft Corp., March 18, 1959. It is perhaps significant that a large sign behind the mockup in the McDonnell factory said, "When a change is not necessary, it is necessary not to change."

[41] Minutes, "Model 133 Mockup Review," McDonnell Aircraft Corp., March 18, 1959.

[42] Memos, Gilruth to STG/Langley Research Center, "Coordination of Meetings of Study Panels . . . ," March 20, 1959; and "Establishment of Capsule Coordination Office and Review Board," June 19, 1959; John H. Disher, interview, Washington, Sept. 2, 1965. For an overview of the nature and scope of Project Mercury as seen by STG at this time, see memo for files [and distribution among supporting groups], Purser, "General Background Material on Project Mercury," March 23, 1959.

[43] Ms., C. F. Bingman for Project Mercury Technical History Program, "Organization," June 3, 1963, 5, 14. See also STG/Langley, "Status Report No. 2."

[44] Senator Stuart Symington's remark is in *Governmental Organization for Space Activities*, 28. Cf. House Committee on Appropriations, 86 Cong., 1 sess. (1959), *National Aeronautics and Space Administration Appropriations, Hearings,* testimony of Hugh L. Dryden, 9. Faget recalled in interview the "family joke" of the symbols: NA¢A → NA$A.

[45] Memo, MacDougall to Project Manager, "Estimated Cost of Manned Space Capsule Contract," Dec. 15, 1958; MacDougall, interview, Feb. 5, 1965.

[46] Silverstein, marginal notes on memo, Low to Dir. for Space Flight Development, March 12, 1959; MacDougall, interview, Sept. 13, 1965.

[47] Memo for files, Meyer, "Visit of McDonnell Representatives to Discuss Spare Parts and Ground Support Equipment," March 10, 1959. See also Ms., G. F. Bailey and S. A. Armstrong for Project Mercury Technical History Program, "Outline of the History of the Mercury Contract," April 8, 1963.

[48] Low, "Status Report No. 8—Project Mercury," March 4, 1959. Cf. Low, "Status Report No. 4." The extent of redesign work to "man-rate" the Atlas was more quickly recognized by its fabricators than by its new customers; Williams interview.

[49] Memo, Purser to Gilruth, "Analysis of Army Ordnance Missile Command Revised Funding Estimate for Redstones and Jupiters," June 5, 1959.

[50] Letter, Glennan to Neil H. McElroy, July 14, 1959. Administrator Glennan began to keep a desk diary in December 1958 [not available to this author], which carefully noted each day's transactions thereafter.

[51] Low, "Status Report No. 14—Project Mercury," May 22, 1959. De Marquis Wyatt, interview, Washington, Sept. 1, 1965; Bond interview.

[52] Ms., William M. Bland, Jr., for Project Mercury Technical History Program, "The Birth of Little Joe Booster"; memo for files, Charles H. McFall, Jr., "Project Little Joe: Ground Instrumentation Required," April 15, 1959.

[53] Memo for files, Sandahl, "Progress on

Little Joe," Feb. 16, 1959; memo for files, Bland, "Results of Trip," May 19, 1959.

[54] Purser, log for Gilruth, Jan. 12, 1959; memo, Charles B. Rumsey to Assoc. Dir., "Meeting to Discuss Project Mercury Problems to Which PARD Rocket Firings Might Contribute Information at an Early Date," Feb. 24, 1959. William E. Stoney, interview, Houston, Feb. 13, 1964. For Scout's capabilities, see "Considerations Affecting Satellite and Space Probe Research with Emphasis on the 'Scout' as a Launch Vehicle," NASA Technical Report R-97, Washington, 1961.

[55] Purser log, Jan. 12, 1959. Cf. *NASA Appropriations, Hearings,* testimony of Dryden, 83–115. Wesley L. Hjornevik, interview, Houston, Feb. 17, 1964.

[56] "Canadian Personnel Chart: Duty Assignments, Need to Know, Travel Requirements," STG, April 1959; Purser, log for Gilruth, April 21, 1959. Bringing fresh insight and seasoned experience to aid STG, this group included two, John D. Hodge and Jack Cohen, of rank equivalent to civil-service rating GS–14. Several more Anglo-Canadian engineers later joined STG.

[57] Purser, log for Gilruth, April 27, 1959. See also documents signed by Glennan, Silverstein, and T. E. Jenkins, Administrative Officer of Goddard Space Flight Center, published as Exhibits 10, 11, and 12 of Appendix D in Alfred Rosenthal, *The Early Years: Goddard Space Flight Center, Historical Origins and Activities through December 1962* (Washington, 1964), 35.

[58] Glennan, interview with Eugene M. Emme, Cleveland, April 6, 1965; Purser, log for Gilruth, May 20, 1959.

[59] House Committee on Science and Astronautics, 86 Cong., 1 sess. (1959), *Basic Scientific and Astronautic Research in the Department of Defense,* testimony of Dr. Herbert F. York, June 4, 1959, 16; B. Porter Brown, interview, Cape Kennedy, April 30, 1964.

[60] Francis E. Jarrett, Jr., and Robert A. Lindemann, "Historical Origins of NASA's Launch Operations Center to July 1, 1962," Kennedy Space Center, Historical Monograph No. 1 (KHM–1), Oct. 1964. There is a dispute over proper nomenclature regarding the combination of launch complexes 5 and 6 into "No. 56." If the latter is a misnomer, it was so commonly used as to justify its use throughout this work.

[61] Memo for files, Emil P. Bertram, "NASA Space Requirements at MFL," April 7, 1959. For an account of the ill-fated Vega vehicle, see Evert Clark, "Vega Study Shows Early NASA Problems," *Aviation Week,* LXXII (June 27, 1960), 62–68.

[62] Scott H. Simpkinson, interview, Houston, June 2, 1964. Hangar S had been built by NRL for Project Vanguard in the face of earlier housing shortages for checkout facilities.

[63] Purser, logs for Gilruth, June 15 and 29, 1959.

[64] Ashton Graybiel, et al., "An Account of Experiments in Which Two Monkeys Were Recovered Unharmed After Ballistic Space Flight," *Aerospace Medicine,* XXX (Dec. 1959), 871–931. Cf. Siegfried J. Gerathewohl, *Principles of Bioastronautics* (Englewood Cliffs, N.J., 1963), 100–108. NASA press releases on primate flights always carried notice of the birthplaces of the subjects to avoid offending Hindus, who believe in transmigration of souls. Presumably 100 percent American monkeys were always 100 percent American. See also p. 53.

[65] Gilruth, speech, Space Age Conference, World Congress of Flight, Las Vegas, April 17, 1959.

[66] "Project Mercury Discussion," 50-page collection of graphic charts and outlines, STG, May 18, 1959, 1.

[67] Memo, Warren J. North to Administrator, "Background of Project Mercury Schedules," with enclosure, Aug. 14, 1960.

[68] It seems fitting to note here the Air Force viewpoint on this period. Max Rosenberg, Chief, USAF Historical Division Liaison Office, has commented as follows on this section (Oct. 8, 1965): "Within these pages is the story of the major crux of program slippages, which seems not to be recognized. There is detailed listing of each agency's role but no recognition that no one was in charge of *total system* analysis, *total system* design, *total system* engineering, *total system* technical direction. This was one of the features of the Air Force ballistic missile program wherein Ramo-Wooldridge functioned as the *systems* engineering and technical director. The lack of such an agency within the Mercury program was understandable, for NASA was without experience in undertakings of such scope and magnitude, but it should be recognized and recorded historically as an expensive 'lesson learned' that cost NASA (and the United States) perhaps a year or more in meeting the Mercury goals." P. 13.

[69] "Project Mercury Discussions," 22–25. Cf. "Main Results of NASA-McDonnell-

ABMA Conference of 11 February 1959," ORDAB-DSRW. CAA 59358, Ballistic Missile Agency; and memo, Purser to Gilruth, "Project Mercury Meeting on February 11, 1959, at ABMA," Feb. 17, 1959.

[70] See transcript of press conference, "Introduction of the Astronauts," April 9, 1959; NASA news releases 59–111, April 7, and 59–113, April 9, 1959; and memo for the record, Allen O. Gamble, "News Story Concerning Astronaut Selection," Feb. 2, 1962.

[71] The "Project Mercury Information Plan," issued in June 1959 at NASA Headquarters, gave overall responsibility for information activities to Walter T. Bonney, Director, Office of Public Information, NASA. The significant decision to divide "official duties" from "personal stories" was made in Washington with the promulgation of "NASA Policy Concerning Mercury Astronauts," May 11, 1959. See also Walter T. Bonney, comments, Dec. 1, 1965.

[72] The distinction between senior pilots and professional test pilots took a quantum leap after 1953 with the introduction of "century series" aircraft. Donald K. Slayton, interview, Dec. 16, 1964. Cf. John Dille, ed., *We Seven, by the Astronauts Themselves* (New York, York, 1962), 70.

[73] For criteria, see p. 131. For the best overview of selection philosophy and program arrangements see Ms., Robert B. Voas, "Preliminary Draft of Astronaut Selection Section, Mercury Technical History," Aug. 28, 1963. Cf. Stanley C. White, interview, San Antonio, Aug. 20, 1965, and Donlan, comments, Sept. 3, 1965.

[74] Low, "Status Report No. 7—Project Mercury," Feb. 17, 1959. Cf. Low, "Status Report No. 6," Feb. 3, 1959.

[75] See David H. Beyer and Saul B. Sells, "Selection and Training of Personnel for Space Flight," *Journal of Aviation Medicine*, XXVIII (Feb. 1957), 1–6. On the Lovelace Clinic as a parallel institution to Mayo Clinic, see brochure, "Lovelace Foundation for Medical Education and Research" (Albuquerque, undated [about 1958]).

[76] Letter, A. H. Schwichtenberg, Head, Aerospace Medical Dept., Lovelace Foundation, to Charles J. Donlan, Nov. 5, 1959.

[77] Voas, "Astronaut Selection," 26. See also Mae M. Link, *Space Medicine in Project Mercury*, NASA SP-4003 (Washington, 1965), Chapter V, "Medical Aspects of Astronaut Selection and Training," 44–59.

[78] Charles L. Wilson, ed., "Project Mercury Candidate Evaluation Program," Technical Report 59–505, Wright Air Development Center, Dec. 1959. Cf. letters, Donlan to David K. Trites, Sept. 22, 1959; and Trites to Donlan, "Summary of Psychological Testing of Candidates for Project Mercury," undated.

[79] Quoted in letter, Donlan to NASA Hq., Dec. 16, 1960.

[80] George E. Ruff, "Medical Criteria in Space Crew Selection," 108th annual meeting, American Medical Assn., Atlantic City, June 9, 1959. Donlan, interview, Langley Field, Va., Jan. 7, 1964, and comments, Sept. 3, 1965. Stanley White vigorously disagreed with this assessment, saying that medical and psychological interviews "were equally important." White interview.

[81] NASA/MSC news release, "Biography of John A. Powers," Jan. 1963. Cf. memo, Powers to Project Director, "Project Mercury Public Affairs Officer," June 9, 1959, which encloses the initial public relations plan for STG.

[82] House Committee on Science and Astronautics, 86 Cong., 1 sess. (1959), *Meeting with the Astronauts (Project Mercury-Man-in-Space Program)*, May 28, 1959, passim. See also "How to Get a Man Up into Space and Back Again," and "Space Voyagers Rarin' to Orbit," *Life*, XLVI, April 20, 1959.

[83] Quoted but unidentified in George E. Ruff and Edwin Z. Levy, "Psychiatric Evaluation of Candidates for Space Flight," *American Journal of Psychiatry*, CXVI (Nov. 1959), 391. For the philosophers, see *The Basic Writings of Bertrand Russell, 1903–1959*, edited by Robert E. Egner and Lester E. Denoun (New York, 1961), 15, 565–576; Teilhard de Chardin, *The Phenomenon of Man* (New York, 1959), 250, 286, and passim; Walter Kaufmann, *Critique of Religion and Philosophy* (Garden City, N.Y., 1961), 429.

[84] This ends an interesting prose poem by David Greenfield entitled "Which Way Is Heaven?" that appeared in *Saturday Review*, XLII (July 4, 1959), 39, reflecting a significant popular shift in perspective related to the announcement of the astronauts' selection. Greenfield wrote, "Heaven has always existed in the mind of man as the abode of spiritual beings and the ultimate destination of believers. Its location has always been 'up'. . . . And now at last man is about to ascend physically into this heaven. . . . Will his spiritual outlook be changed by a shock of disillusion? . . ."

## *Chapter VII*

[1] In considering how both technology and techniques began to evolve through the planning and tooling stages and into manufacturing and production, this chapter and the next make the conventional yet conceptually useful distinction between mechanical and human (factors) engineering endeavors. Another important distinction, that which rated pilot safety first and mission success second, was implicit from the start, but became explicit in the production programs only after many technical arguments and much rethinking. The process of man-rating the machines is meant to suggest all the efforts made to perfect a completely automatic system for Earth-orbital flight. The reciprocal process of machine-rating men is meant to focus on the ambiguities in the idea of perfecting a completely automated system for such purposes. Chronologically this division coincides with the major, but by no means singular, concern of those responsible for the execution of Project Mercury during the year of development between the summers of 1959 and 1960.

[2] House Select Committee on Astronautics and Space Exploration, 86 Cong., 1 sess. (1959), *The Next Ten Years in Space, 1959–1969,* report by T. Keith Glennan, Hugh L. Dryden, Abe Silverstein, John P. Hagen, and Homer E. Newell, Jr., 120.

[3] Obituary for Paul D. Taylor, *Airscoop,* Langley Research Center, May 15, 1959. Regarding overtime, see Ms., Paul E. Purser, "Discussion of Project Mercury History and Schedules," Aug. 1960.

[4] "Complement Analysis," STG, Appendix C of confidential staff study, July 10, 1959, C–10.

[5] See James M. Grimwood, *Project Mercury: A Chronology,* NASA SP–4001 (Washington, 1963), 215. Cf. memos, Robert R. Gilruth to staff, "Appointment of Associate Directors," Sept. 15, 1959; and "Organization of Space Task Group," Aug. 10, 1959.

[6] For most of the preliminary operational planning, see the appendices and annexes to Ms., *"Overall Plan:* Department of Defense Support for Project Mercury," undated [ca. Sept. 1959]. See also DOD Representative for Project Mercury Support Operations, *Final Report to the Secretary of Defense on Department of Defense Support of Project Mercury: For the Period 1 July 1959 through 13 June 1963;* approved by Leighton I. Davis, Maj. Gen., USAF, 11 Sept. 1963. The major exceptions to Maj. Gen. Donald N. Yates' responsibility for military support activities for Mercury were in the areas of man-rating the Atlas and bioastronautical research and training.

[7] Maxime A. Faget recalls Walter C. Williams' being adamantly opposed to vertical manned rocket launches in 1957, but by mid-1958 Williams was supporting the Langley plans on the joint NACA-Advanced Research Projects Agency panel. Faget, interview, Houston, Aug. 4, 1964, and Williams, Aug. 23, 1965. See also memo, Gilruth for staff, "Appointment of Associate Directors," Sept. 15, 1959.

[8] Joachim P. Kuettner, "Manrating Space Carrier Vehicles," in Ernst Stuhlinger et al., eds., *From Peenemünde to Outer Space: Commemorating the Fiftieth Birthday of Wernher von Braun* (Huntsville, Ala., 1962), 629–630. See also "Biographic Sketch: Dr. Joachim P. Kuettner," Marshall Space Flight Center, May 1, 1963; Kuettner, interview, Huntsville, April 28, 1964.

[9] Memo, Kuettner to "all labs," Development Operations Division, Army Ballistic Missile Agency, "Mercury-Adam Project," Jan. 14, 1959; Kuettner, "Mercury Project," draft status report, May 21, 1959. Cf. typescript prospectus, Kuettner, "ABMA's Participation in the Mercury Project," undated [about Aug. 1959]. See also memo, A. Richard Felix to Dir., Aeroballistics Lab., "Visit to NASA, Langley Concerning Future Wind Tunnel Tests of the Jupiter-C Boosted Manned Space Capsule," Jan. 15, 1959; and Mack W. Shettles, "Status Report—Project Mercury," ABMA report No. DFE–IN–09–59, Feb. 13, 1959. Cf. memo, Dieter Grau to "M–G&C–DIR," "Unsatisfactory Condition on MR Abort Sensing System," Oct. 11, 1960.

[10] F. W. Brandner, "Proposal for Mercury-Redstone Automatic Inflight Abort Sensing System," Army Ballistic Missile Agency report No. DG–TR–7–59, Redstone Arsenal, June 5, 1959, 1.

[11] See, for example, letter, James D. Sams to CO, ABMA, "Project Mercury-Redstone Delineation of Responsibility," Oct. 8, 1959; memo, C. J. Kronauer, to Capt (?) Hombaker, "Project Mercury Schedule Notification," Oct. 12, 1959; Debus to Kuettner, "NASA–ABMA–AFMTC Project Mercury Operating Agreement," Nov. 9, 1959; letter, Gen. John B. Medaris to Yates, Dec. 10, 1959; Yates to Medaris, Dec. 21, 1959.

[12] Brig. Gen. Homer A. Boushey in *The*

*Next Ten Years in Space*, 30.

[13] John R. Pierce quoted sympathetically by Carl Dreher, "Pie in the Sky: Scramble for the Space Dollar," *The Nation*, CXC (Feb. 13, 1960), 133. Such extreme positions were denounced by at least one independent engineer, viewing the man-in-space program in the October issue of the trade journal *Automatic Control*. For reprint, see George K. Arthur, "Why Man in Space?—An Engineer's View," in Richard M. Skinner and William Leavitt, eds., *Speaking of Space: The Best from Space Digest* (Boston, 1962), 142.

[14] Bernhard A. Hohmann, interviews, El Segundo, Calif., Aug. 25, 1964, and Houston, Sept. 16, 1965; E. B. Doll, telephonic interview, El Segundo, Aug. 25, 1964; D. R. White, interview, Houston, Aug. 10, 1964. For an overview of the business evolution from Thompson Ramo Wooldridge into Space Technology Laboratories and Aerospace Corporation see Robert Sheehan, "Thompson Ramo Wooldridge: Two Wings in Space," *Fortune*, LXVII (Feb. 1963), 95–99, 139–146. See also House Committee on Government Operations, 87 Cong., 1 sess., *Air Force Ballistic Missile Management (Formation of Aerospace Corporation)*, report No. 324, May 1, 1961.

[15] See [Henry B. Kucheman, Jr.] "Reference File, AFBMD Support, Project Mercury," bound folder of documents, Air Force Space Systems Div., El Segundo, Calif., Jan. 4, 1961; Frank Wendzel and R. W. Keehn, interviews, San Diego, Calif., Aug. 28, 1964. For a description of advances in manufacturing techniques, see Richard Sweeny, "Atlas Generates Fabrication Advances," *Aviation Week*, LXXII (Jan. 4, 1960), 38–49. For an overview of the actors within the BMD–STL–GD/A complex, see transcript, "Proceedings of the Mercury-Atlas Booster Reliability Workshop," GD/A, San Diego, Calif., July 12, 1963, passim.

[16] White interview; Philip E. Culbertson, comments, Aug. 16, 1965. Cf. Convair/Astronautics Report No. AZM–27–321, "Test Equipment for Abort Sensing and Implementation System for Mercury Atlas Flight," July 17, 1959.

[17] Donald K. Slayton, speech, annual meeting, Soc. of Experimental Test Pilots, Los Angeles, Oct. 9, 1959.

[18] Christopher C. Kraft, Jr., "A Review of Knowledge Acquired from the first Manned Satellite Program," MSC fact sheet No. 206, 1.

[19] John P. Mayer and Carl R. Huss, "Trajectory Analysis," in *Mercury Project Summary, Including Results of the Fourth Manned Orbital Flight, May 15 and 16, 1963*, NASA SP–45 (Washington, 1963), 119; John M. Eggleston, "Some Abort Techniques and Procedures for Manned Spacecraft," *Aerospace Engineering*, XXI (Nov. 1962), 17.

[20] Paul A. Campbell, "Man in Space—Where We Stand," *Air Force and Space Digest*, (July 1959), reprinted as Part 3 of Appendix B in Senate Committee on Aeronautical and Space Sciences, 86 Cong., 1 sess. (1959), report No. 1014, *Project Mercury: Man-in-Space Program of the National Aeronautics and Space Administration*. Cf. Siegfried J. Gerathewohl and George R. Steinkamp, "Human Factors Requirements for Putting a Man in Space," paper, ninth International Astronautical Congress, Amsterdam, Aug. 1958.

[21] Perhaps the classic basic text for the modern revival of efficiency expertise was dedicated, both formally and in a limited sense financially, to Glennan by the authors, all professors in the operations research group at Case Institute of Technology since 1952: C. West Churchman, Russell L. Ackoff, and E. Leonard Arnoff, *Introduction to Operations Research* (New York, 1957). See also Maurice Sasieni, Arthur Yaspan, and Lawrence Friedman, *Operations Research—Methods and Problems* (New York, 1957); James H. Batchelor, *Operations Research: An Annotated Bibliography* (2 ed., St. Louis, 1959–1963), Vols. I, II, III, and IV.

[22] S. E. Skinner, Executive Vice Pres., General Motors Corp., "Quality and Reliability Control," speech, first General Motors-wide orientation program, July 23, 1959. For a description of the Atlas reliability problem, see Robert De Roos, "Perspective '64," booklet (General Dynamics/Astronautics, 1964).

[23] See Joan R. Rosenblatt, "On Prediction of System Performance from Information on Component Performance," *Proceedings of the Western Joint Computer Conference*, Los Angeles, Feb. 1957. Cf. Nicholas E. Golovin, "An Approach to Reliability Prediction Program," American Society for Quality Control, *Transactions of 1960 Convention*, San Francisco, May 25, 1960.

[24] Thomas C. Reeves, "Reliability Prediction—Its Validity and Application as a Design Tool," paper No. 60–MD–1, American Soc. of Mechanical Engineers, Feb. 10, 1960, 8.

[25] George M. Low, in comments, Oct. 5, 1965, notes that these discussions "occurred not between Washington and the Field but between the organization responsible for manned space flight both in Washington and the Field and the Reliability people."

[26] Harry R. Powell, "The Impact of Reliability on Design," paper No. 60–MD–2, American Soc. of Mechanical Engineers, April 5, 1960.

[27] See Wernher von Braun, "The Redstone, Jupiter, and Juno," in Eugene M. Emme, ed., *The History of Rocket Technology: Essays on Research, Development, and Utility* (Detroit, 1964), 107–121; Kuettner interview. On the little known Redstone booster recovery system development efforts, see R. I. Johnson et al., "The Mercury-Redstone Project," MSFC Saturn/Apollo Systems Office, TMX 53107, June 1964, 6–22, 6–29; letter, Gilruth to von Braun, with enclosures, Dec. 9, 1959; memo, R. M. Barraza for M–DEP–R&D, MSFC, "Summary of Mercury-Redstone Recovery Program," Aug. 1, 1960.

[28] For details of Redstone and Jupiter flight failures, see three reports prepared by Chrysler Missile Division for MSFC, "Overall Study and Flight Evaluation of the Redstone Missile Propulsion and Associated Systems," MSFC report No. RP–TR–61–11, April 7, 1961; G. G. McDonald, P. R. Brown, and J. L. Montgomery, Jr., "Jupiter Missile and Juno II Vehicle Malfunction Study," MSFC report No. MTP–M–P&VE–P–2–62, April 26, 1962; and P. S. Sorce, L. Van Camp, R. E. Stevens, et al., "Redstone Vehicle Malfunction Study (Mercury-Redstone Program)," MSFC report No. DSD–TM–12–60, Original Issue, June 15, 1960; Rev. A, Oct. 31, 1960, Rev. B, May 1, 1961.

[29] Joachim P. Kuettner and Emil Bertram, "Mercury-Redstone Launch Vehicle Development and Performance," in *Mercury Project Summary*, 69. See also Brandner, "Proposal for Abort Sensing System," 4, 5. For STG's first reliability meeting with ABMA, see Purser, log for Gilruth, July 27, 1959. On Chrysler's role, see two brochures, "Redstone," AB 106, Chrysler Missile Division [ca. April 1961], and "Presentation to Manned Spacecraft Center," Chrysler Defense and Space Group, June 20, 1962.

[30] "Project Mercury Indoctrination," report No. 6821, McDonnell Aircraft Corp., May 21, 1959, 160.

[31] "Reliability Program Status for Project Mercury," report No. 7007, McDonnell Aircraft Corp., Aug. 17, 1959, 1, 11, 12.

[32] Tecwyn Roberts, "Minutes of Meeting: Presentation by AFBMD/STL on Safety and Reliability," Nov. 13, 1959, with enclosures. Powell's chart is enclosure 2. Cf. John C. French and Frederick J. Bailey, Jr., "Reliability and Flight Safety," *Mercury Project Summary*, 105–116, for a static view of the results of these discussions.

[33] Ms., F. J. Bailey, Jr., "Reliability and Flight Safety Problems of Manned Spacecraft Flight," April 4, 1962, 5. The crux of the reliability dispute between "statistics," represented by Golovin and NASA Headquarters, and "techniques," represented by STG, McDonnell, and ABMA, was illustrated by the basic commitment among STG engineers to deny the existence of any such thing as "a random failure." Gilruth later expressed this particular attitude toward man-rating machines: "We must regard every malfunction and, in fact, every observed peculiarity in the behavior of a system as an important warning of potential disaster. Only when the cause is thoroughly understood, and a change to eliminate it has been made, can we proceed with the flight program." See Gilruth, "MSC Viewpoints on Reliability and Quality Control," MSC fact sheet No. 93, 1963.

[34] See Purser, log for Gilruth, Aug. 5, 1959.

[35] Charles W. Mathews, interview, Houston, Feb. 24, 1964. Cf. memo, William M. Bland, Jr., and Kraft to Project Dir., "Meeting with Range Safety People at AFMTC, March 31, 1959," April 3, 1959.

[36] Ms., Mathews, "Mercury Abort Sensing and Implementation Systems: History of Development," outline for Project Mercury Technical History Program, July 1, 1963; Kuettner and Bertram, "Mercury-Redstone Launch Vehicle," 72; Kuettner, "Manrating Space Carrier Vehicles," 636.

[37] Compare the detail and progress evidenced in "Status Report No. 3 for Period Ending July 31, 1959," Langley/STG, with that shown in "Status Report No. 4 for Period Ending Oct. 31, 1959," Langley/STG.

[38] Letter, Gilruth to Commanding Officer, Army Ballistic Missile Agency, "Mercury-Redstone Launch Schedule," Aug. 25, 1959. Cf. memo, Purser to Project Dir., "Project Mercury Meeting on 11 February, 1959, at ABMA," with enclosed bar chart. See C. Northcote Parkinson, *Parkinson's Law* (New York, 1959).

[39] Perhaps the most eloquent defense Wernher von Braun ever made against the inevitable shallow cynicism of critics who could not forget the Second World War was a widely printed article entitled "The Acid Test," which first appeared in *Space Journal of the Astro-Sciences*, Vol. 1, No. 3 (Summer 1958), 31–36. For background on the following discussion of

the von Braun team's cohesive esprit, see Walter R. Dornberger, *V–2* (New York, 1954); and Dieter K. Huzel, *Peenemünde to Canaveral* (Englewood Cliffs, N.J., 1962).

[40] For part of the controversy generated by the Mercury-Jupiter cancellation, see letter, John G. Zierdt to NASA Administrator, June 26, 1959; memos, Low to Silverstein, "Cancellation of Mercury-Jupiter Program," July 8 and July 13, 1959; message, Zierdt to Silverstein, July 16, 1959; letters, Silverstein to Medaris, Commanding Officer, Army Ordnance Missile Command, July 21 and July 28, 1959; letter, Herbert F. York to Glennan, Aug. 4, 1959; letter, David H. Newby to Low, Aug. 19, 1959. See also letters, Gilruth to Low, July 1, 1959; Silverstein to Gilruth, July 1, 1959; and Gilruth to Silverstein, July 8, 1959. Memo for files, John A. Powers, "Response to Query on the Subject of Cancellation of Jupiter," Aug. 31, 1959.

[41] George Savignac and E. G. Leever, "Project Mercury Engineering Status Report," McDonnell Aircraft Corp., Aug. 1, 1959, 31; Savignac and Leever, "Bi-Monthly Engineering Status Report," McDonnell Aircraft Corp., Oct. 1, 1959, 39.

[42] Minutes, "Mercury Panel 3 Meeting, 18–19 August, 1959, at Missile Firing Laboratory, Cape Canaveral, Florida." These minutes record numerous bilateral agreements on flight testing, range safety, etc., concurred in by NASA, McDonnell, and Army Ballistic Missile Agency representatives. See especially Part IV, an appendix on operational checkout procedures. Kuettner, "Minutes and Major Results of Project Mercury Coordination Meeting at ABMA," Nov. 20, 1959. Cf. minutes, Jerome B. Hammack, Redstone systems engineer, STG, "Mercury-Redstone Panel II Meeting: Booster and Capsule Checkout Procedures, at ABMA, Nov. 19, 1959," Dec. 8, 1959; message, M. L. Raines to Commanding General, AOMC, Nov. 3, 1959; reply, PR–092200Z, Nov. 9, 1959.

[43] See House Committee on Science and Astronautics, 86 Cong., 2 sess. (1960), *Transfer of the Development Operations Division of the Army Ballistic Missile Agency to the National Aeronautics and Space Administration, Hearings,* Feb. 3, 1960; Robert L. Rosholt, *An Administrative History of NASA, 1950 to 1963;* David S. Akens, Paul K. Freiwirth, and Helen T. Wells, *History of the George C. Marshall Space Flight Center* (Huntsville, Ala., 1960–1962), I, ix.

[44] White, "Development of the Mercury-Atlas Pilot Safety Program," Space Technology Laboratories, June 12, 1961, 4. Cf. Hohmann, "General Aspects of the Pilot Safety Program for Project Mercury Atlas Boosters," Space Technology Laboratories, Feb. 8, 1960, passim. Cf. "System Description—Abort Sensing and Implementation System for Project Mercury," Convair/Astronautics report No. AE60–0576, June 6, 1960.

[45] See C. L. Gandy and I. B. Hanson, "Mercury-Atlas Launch Vehicle Development and Performance," in *Mercury Project Summary*, 94. James R. Dempsey, a vice president of General Dynamics and the manager of its Convair division, later called attention to the 25 percent design safety factor commonly used in the ballistic missile business versus the 1.5 safety margin used in the design of aircraft. See his paper "Launch-Vehicle Considerations for Manned Space Flight," in *Proceedings of First National Conference on the Peaceful Uses of Space*, Tulsa, Oklahoma, May 26–27, 1961 (Washington, 1961), 118.

[46] P. E. Culbertson, "Man-Rating the Atlas as a Mercury Booster," American Institute of Aeronautics and Astronautics, paper No. 65–252, presented at Dayton, Ohio, April 21–23, 1965, 2, 7.

[47] Hohmann interviews and article, "Pilot Safety and Mercury/Atlas," *Astronautics and Aerospace Engineering* (Feb. 1963), 40–42.

[48] Minutes, "Mock-Up Review," 12 through 14 May, 1959, with enclosure addressed to C. H. Zimmerman and Low, June 23, 1959.

[49] Faget interviews; John F. Yardley, interview, St. Louis, Aug. 31, 1964; and MAC "Biographical Information" on Yardley, June 10, 1964. Until the redesignation of STG as MSC on Nov. 1, 1961, and the reorganization of MSC into the Mercury, Gemini, and Apollo Project Offices on Jan. 15, 1962, systems engineering in STG was shared by the Flight Systems Division and the Engineering Division under Faget and James A. Chamberlin, respectively. See Grimwood, *Mercury Chronology*, 219–220.

[50] McDonnell Aircraft Corporation, "Twentieth Annual Report," June 30, 1959, foreword. Cf. "McDonnell Aircraft Corporation, Nineteenth Annual Report, 1958." "Achievements, 1939–1956," "Orientation Manual, 1960–61," 7, and "McDonnell: The First Twenty-Five Years, 1939–1964," 18–28, brochures, McDonnell Aircraft Corp.

[51] Memo, Logan T. MacMillan to D. S. Lewis, "Project Mercury Daily Report, 18 July 1959—Coordination Committee Results,"

McDonnell Aircraft Corp. inter-office memo No. 344; memo, E. M. Flesh to E. Akeroyd, "Capsule Coordination Committee," McDonnell Aircraft Corp. inter-office memo No. 3606, July 2, 1959. See also message, MacMillan to STG, Sept. 16, 1959. Cf. MacMillan, interview, St. Louis, Aug. 31, 1964.

[52] Kendall Perkins, interview, St. Louis, Aug. 31, 1964.

[53] William Dubusker, interview, St. Louis, Sept. 1, 1964; Flesh, interview, St. Louis, Sept. 2, 1964. For a more detailed description of fabricating technique and fusion welding, see David S. Anderton, "How Mercury Capsule Design Evolved," *Aviation Week*, LXXIV (May 22, 1961).

[54] Regarding the Slayton-Carpenter dispute over the best kind of pilot control system, see John Dille, ed., *We Seven, by the Astronauts Themselves* (New York, 1962), 15. Memo, D. P. Murray, MAC Manager of Contracts, to Project Mercury, Engineering and Contract Administration Division, "Mercury Capsule Contract NAS5–59, Contract Change Proposals Nos. 58–1, 61–2, 73 and 76," Sept. 23, 1959.

[55] Edward R. Jones, interview, St. Louis, Sept. 2, 1964. Jones had earned his doctorate in experimental psychology from Washington University in St. Louis, in 1954, and since the first of the decade he had worked in flight safety research.

[56] Minutes, "MAC Project Mercury—Human Factors; Phase A2, Mission Analysis and Preliminary Cockpit Layout," manuscript minutes of oral report by Minneapolis-Honeywell human factors group to McDonnell, March 2, 1959, 3.

[57] Memo, Jones to Yardley, "Failure Analysis," with enclosure, David T. Grober and Jones, "Human Engineering Implications of Failures in the Mercury Capsule," Aug. 10, 1959. These two quotations are from pp. 2, 4, and 5.

[58] Jones, "Man's Integration into the Mercury Capsule," paper, 14th annual meeting, American Rocket Soc., Washington, Nov. 16–19, 1959, 1, 2.

[59] The input of sense data into the ASCS and its output of nervous commands suggests the classic cybernetic approach to understanding the Mercury attitude control system. Consider the machine as if it were an organism in which sensors (like small rate gyros, larger position gyros, and infrared sensitive horizon scanners) provide the brain (ASCS) with the data it needs to compute through its amplifier-calibrators and logic boards the actions required by the muscles (RCS motors) in order to maintain a certain position. Sense organs, a brain, and muscles are necessary black boxes to the performance of any self-regulating system, but Mercury design engineers seldom bothered at first to produce "glass boxes" for operating engineers to determine how to build, work, and improve them. For a helpful introduction to the intricacies of modern gyroscopes, accelerometers, and inertial guidance systems, see "Inertial Guidance Primer," pamphlet, Minneapolis-Honeywell Regulator Company, 1963.

[60] Robert Chilton, interview, Houston, June 2, 1964; Paul F. Horsman, interview, Houston, Feb. 12, 1964; Thomas V. Chambers and Richard R. Carley, comments, Sept. 25, 1965. See also Horsman draft Ms., "Manned Spacecraft Stabilization and Control System," for Mercury Technical History, June 19, 1963.

[61] Memo for files, Chilton, "Alternate Attitude Control System for the Mercury Capsule," July 8, 1959, 3. Cf. memo, Chilton to Project Dir., "Alternate Attitude Control System for the Mercury Capsule," July 1, 1959. See also Chilton, "Attitude Control Systems," progress report, Oct. 21, 1959.

[62] Kurt P. Wagenknecht, McDonnell Aircraft Corp. procurement officer, interview, St. Louis, Sept. 2, 1964.

[63] Roger J. Pierce, "Mercury Capsule Communications," *Astronautics*, IV (Dec. 1959), 24–27, 86–88. Another constant problem was the discovery of toxic byproducts from electrical insulation, which required much equipment redesign.

[64] Minutes, "Special Coordination Meeting at McDonnell," Norman F. Smith, secretary, Oct. 1 and 2, 1959, sec. 2a.0.1, 5.

[65] Letter, Gilruth to Ira H. Abbott, "Required Basic Research on Parachute to Support Manned Space Flight," July 6, 1959, 2. See also memos, G. A. White, J. B. Lee, and Alan B. Kehlet to Chief, Flight Systems Div., "Drogue parachute," Oct. 15, 1959.

[66] Letter, Henry J. E. Reid to NASA, "Required Basic Research on Parachute to Support Manned Space Flight," Sept. 22, 1959; cf. Joe W. Dodson, transcript of taped discussion, "Mercury Parachute History," Sept. 1962, and Russell E. Clickner, comments, Nov. 5, 1965.

[67] Letter, Charles J. Donlan to Low, "Langley Support for Project Mercury," Dec. 9, 1959. The addition of the better "mousetrap" is best described in Aleck C. Bond and

Kehlet, "Review, Scope, and Recent Results of Project Mercury Research and Development Program," paper, 28 annual meeting, Inst. of Aeronautical Sciences, New York City, Jan. 25, 1960.

[68] Purser, log for Gilruth, Dec. 21, 1959. Parachute systems and technology are well described in Ms., Bond and Faget, "Technologies of Manned Space Systems," Chap. 14, "The Role of Ground Testing in Manned Spacecraft Programs," 166–177.

[69] When they become available, see the following classified historical monographs written by Air Force historians: Lee Bowen, *The Threshold of Space: The Air Force National Space Program, 1945–1959,* Sept. 1960; Max Rosenberg, *The Air Force in Space 1959–60,* June 1962; Clarence J. Geiger, *History of the X–20A: Dyna-Soar,* Air Force Systems Command Hist. Pub. Series, 63–50–I, Oct. 1963; Robert L. Perry, *Origins of the USAF Space Program, 1945–1956,* Air Force Systems Command Hist. Pub. Series, 62–24–10, 1961; Ethel M. DeHaven, *Aerospace—The Evolution of USAF Weapons Acquisition Policy, 1945–1961,* Aug. 1962; *Comparisons of NASA Manned Space Program and USAF Manned Military Space Proposal,* Feb. 25, 1960.

[70] George Alexander, "Atlas Accuracy Improves as Test Program Is Completed," *Aviation Week,* LXXVIII (Feb. 25, 1963), 69–75.

[71] Mark Morton, "Progress in Reentry-Recovery Vehicle Development," pamphlet, Missile and Space Vehicle Dept., General Electric Co., Philadelphia, Jan. 2, 1961, 14.

[72] Kehlet and Bruce G. Jackson, STG aerodynamicists responsible for the aerodynamic stability of the Big Joe capsule on entry, wanted this to be a free flight (with the ACS nonoperative from turnaround to max q), but shortly before the launch day "somebody blew the whistle" and changed the plan to full operation of the ACS throughout the flight. As it turned out, Kehlet and Jackson got their wish after all: interviews, Downey, Calif., Aug. 27, 1964, and Houston, Sept. 13, 1965.

[73] "Project Mercury Status Report No. 4," 1, 15–18, 36. Cf. "Project Mercury Status Report No. 3," Ms., Bond, for Project Mercury Tech. Hist. Program, "Big Joe," June 27, 1963. According to Jack A. Kinzler, Langley shop foreman, the Big Joe capsule culminated an intensive manufacturing development that fed directly into STG's relations with McDonnell; see Kinzler draft Ms., "Manufacturing by NASA for Project Mercury," for Mercury Technical History, Aug. 30, 1963.

[74] Memo, Bond to Project Dir., "Visit to Lewis Laboratory with Regard to Instrumentation and Construction of Big Joe Capsule," April 28, 1959. Cf. Ms., Norman Farmer et al., "Instrumentation," for Project Mercury Tech. Hist. Program, June 27, 1963, 12. Ms., Harold Gold, "Attitude Control System for Project HS–24," June 9, 1959; Warren Plohr, interview, Cleveland, May 1, 1964.

[75] Bond, interview, Houston, March 13, 1964; B. Porter Brown, interview, Cape Kennedy, April 30, 1964; Scott H. Simpkinson, interview, Houston, June 2, 1964. See also memo [Simpkinson], NASA–(MTQD) to all concerned, "Personnel Assignments for First Mercury FRF and Launch," Aug. 31, 1959.

[76] The industrial society at the Cape is well described by Richard A. Smith, "Industry's Trial by Fire at Canaveral," in Editors of *Fortune, The Space Industry: America's Newest Giant* (Englewood Cliffs, N.J., 1962), 65 et seq.

[77] For the first STG countdown procedures, see four-page ditto, "HS–24 Countdown of Major Events," in Simpkinson's papers; STG, "Test No. HS–24 General Information for Recovery Forces," NASA Project Mercury working paper No. 101, Aug. 14, 1959.

[78] The following description of the Big Joe flight is based on the documents cited below and on Simpkinson's eyewitness account and vivid recall in interview; "Preliminary Flight Test Results of Big Joe," NASA Project Mercury working paper No. 107, Oct. 12, 1959; "Qualification Tests on the Big Joe Recovery System," NASA Project Mercury working paper No. 108, Oct. 27, 1959. Cf. memo, Warren J. North to T. E. Jenkins, "Flight Mission Data for Project Mercury," Jan. 14, 1960, and John P. Mayer, comments, Sept. 8, 1965.

[79] Memo, Low to Administrator, "Big Joe Shot," Sept. 9, 1959. Carl R. Huss, in comments, Oct. 5, 1965, called attention to the fact that "the reliability of Atlas staging was about as high as it could be" until Big Joe.

[80] Letter, "Big Joe team" to Gilruth, Sept. 6, 1959. This artifact is one of Gilruth's mementos, now sealed in plastic and framed in a plaque on the wall of the office of the director, Manned Spacecraft Center. See also Huss comments.

[81] Memo, Leonard Rabb to Chief, Flight Systems Div., "Heat Shield Performance," Oct. 7, 1959. Bond, interview, Houston, Sept. 22, 1965. See also "Results of Studies Made to Determine Required Retrorocket Capability,"

NASA Project Mercury working paper No. 102, Sept. 22, 1959. In addition, Alan B. Kehlet directed Dennis F. Hasson to investigate an inflatable sphere to accomplish the decrease in decay time for a retrofire failure and to stabilize the capsule in the event of a control system failure. This study was published as NASA Project Mercury working paper No. 113, "Preliminary Study Using Inflatable Spheres for Aerodynamic Stabilization During Reentry," Nov. 18, 1959.

[52] Bond, "Big Joe," 23, 24, 25. The last paragraph of this quotation is somewhat anachronistic in that it disregards the last-minute debates among aerodynamicists over the dynamic stability issue: see ante footnote 72. Regarding afterbody heat protection, other evidence from wind tunnels and from the Navy's Ordnance Aerophysics Laboratory at Daingerfield, Texas, was accumulating also, pointing toward the need for beryllium or a like material to act as heat sink shingles around the antenna canister.

[53] Alexander, "Atlas Accuracy Improves."

[54] Abraham D. Spinak et al., "Special Accident Investigating Committee Report of the Little Joe No. One Misfire on Aug. 21, 1959, Wallops Station," Sept. 18, 1959, 6.

[55] Memo, W. S. Blanchard, Jr., to Assoc. Dir., "Tentative Changes in the Langley Little Joe Support Program," Sept. 3, 1959; "Little Joe Project Progress Report," North American Aviation, Sept. 31, 1959, 6; letter, Gerathewohl to Jerome Hammack, Dec. 30, 1959; letter, Donlan to Gerathewohl, Jan. 22, 1960.

[56] Memo, Low to Administrator, "First Little Joe Launching," Oct. 5, 1959. Cf. memo, Low to Administrator, "Follow-up Report, Little Joe Firing of 11/4/59," Nov. 6, 1959. See "Flight Test Report LJ–6," NASA Project Mercury working paper No. 133, April 22, 1960. See also memo, John F. Royall, Jr., to STG Assoc. Dir., "Preliminary Data from the Flight Test . . . of Little Joe No. 6, Nov. 4, 1959."

[57] "Countdown for the Little Joe 1–A," STG, Nov. 4, 1959. Cf. memo, Silverstein to Dir., Office of Public Information, "Project Mercury Information Plan," July 7, 1959.

[58] Letter, Donlan to Cdr., DesFlotFour, Dec. 29, 1959; "Research and Development Flight Test Program . . . Abort at High Dynamic Pressure, LJ–1A," NASA Project Mercury working paper No. 134, July 25, 1960. George Low has commented (Oct. 5, 1965) that this hangfire on LJ–1A "probably in itself made the entire Little Joe program worthwhile. Early identification of this problem certainly saved us time and avoided many headaches later."

[59] "Minutes of Meeting, Bio-Paks for Little Joe Flights 2, 3, and 4, June 8, 1959, at STG," June 18, 1959. Cf. memo, Jack C. Heberlig to Gilruth, "Visit of [School of Aviation Medicine personnel, 25 men] to Discuss Bio-Paks [for Little Joe 2, 3, and 4]," April 1, 1959. Ronald Kolenkiewicz, "Minutes of Meeting Concerning Mercury Qualification Test for Little Joe No. 5, June 30, 1959, at NASA-STG, Langley Field, Va.," July 16, 1959. The preliminary operations plan for the aeromedical aspects of LJ–5 was drawn up by Richard S. Johnston on Nov. 26, 1959.

[60] The possibility of flying a manned Little Joe was seriously if secretly considered during this time, but the idea was quickly discarded as technically not feasible because the dynamic pressures were too great: Walter C. Williams, interview, Houston, Aug. 23, 1965.

[61] "Little Joe II," operations plan, STG, Dec. 2, 1959; memo, Low to Administrator, "Little Joe Test No. 3," Dec. 5, 1959. Cf. "Flight Test Report, LJ–2," NASA Project Mercury working paper No. 169, April 1961. "Recovery Operations for Little Joe Test No. Two," NASA Project Mercury working paper No. 122, Jan. 18, 1960. See also letter, Dryden to Gilruth, Dec. 8, 1959; letter, Otis O. Benson, Jr., to Dryden, Dec. 30, 1959.

[62] Memo, George D. Smith to NASA Administrator, "Biological Experiment on Little Joe No. 2," Dec. 31, 1959. Cf. letter, Reid to STG, "In support of Project Mercury—Transmittal of Preliminary Data . . . of Little Joe 2," Dec. 31, 1959; John A. Powers and E. Harry Kolcum, "Information Plan—Little Joe Flight 1–B," Jan. 5, 1960, 2.

[63] Gilruth, "Addendum to Information Plan for Firing of Little Joe 1–B," Jan. 5, 1960, 2.

[64] Memo, Low to NASA Administrator, "Little Joe 1–B (Test No. 4)," Jan. 22, 1960. Cf. "Flight Test Report, LJ–1B," NASA Project Mercury working paper No. 173, March 3, 1961. "Recovery Operations for LJ Test No. One–B," NASA Project Mercury working paper No. 105, Feb. 1960.

[65] Memo, Heberlig to Chief, Flight Systems Div., "Preliminary Reports of the SAM Bio-Pak Experiment in Little Joe 1–B," Feb. 3, 1960. See also letter, Gilruth to Cloid D. Green, School of Aviation Medicine, Brooks AFB, re LJ–1B biophysical aspects, April 27, 1960.

[66] Memo, Harvey H. Hubbard to Assoc.

Dir., STG, "Noise Measurements of Big Joe and Little Joe Mercury Vehicles," Feb. 17, 1960. Cf. letter, Donlan to McDonnell Aircraft Corp., re preliminary results of LJ–1B and LJ–2 compiled for use in production redesign, May 3, 1960. See also booklet, "Project Mercury Photographs of Press Tour, Little Joe 1–B," Jan. 20–21, 1960.

[97] Minutes, Lewis R. Fisher, "Little Joe No. 5," meeting on Jan. 28, 1960.

[98] See, e.g., *Newsweek,* LIV (Oct. 26, 1959), for story and pictures of three Russian cosmonauts, Aleksei Gracher, Aleksei Belokonev, and Ivan Kachur. See also Ari Shternfeld, *Soviet Space Medicine* (2 rev. ed., New York, 1959).

[99] Purser, logs for Gilruth, Dec. 15 and 21, 1959.

[100] Memo, M. Scott Carpenter et al., to Project Dir., "Exchange of Visits with Russian Astronauts," Oct. 21, 1959; T. Keith Glennan, "Opportunities for International Cooperation in Space," *Dept. of State Bulletin* (Jan. 11, 1960), 62. Cf. Vernon Van Dyke, *Pride and Power* (Urbana, Ill., 1964), 244–246; Eugene M. Emme, *Aeronautics and Astronautics: An American Chronology of Science and Technology in the Exploration of Space, 1915–1960* (Washington, 1961), 115. See also Philip C. Jessup and Howard J. Taubenfeld, *Controls for Outer Space and the Antarctic Analogy* (New York, 1959), 251–282; Purser, "Review of Information Relating to Soviet Manned Space Flight Activity," a scrapbook and summary report, Jan. 22, 1960.

[101] Howard C. Kyle, interview, Houston, Oct. 19, 1963; Hartley A. Soulé, interview, Hampton, Va., Jan. 7, 1964. Perhaps the best overview of the complexity of the Mercury network can be gained from the manual "Introduction to Project Mercury and Site Handbook," Western Electric Company, Inc., MG–101, Sept. 1960. This is the first in a series of some 50 volumes of operations and maintenance manuals.

[102] Kraft, "Some Operational Aspects of Project Mercury," speech, annual meeting, Soc. of Experimental Test Pilots, Los Angeles, Oct. 9, 1959, 5, 6, 10. See also Kraft, interview, Houston, Oct. 20, 1964, and "A Study of the Control and Landing Areas for Post Staging Abort Trajectories," NASA Project Mercury working paper No. 100, Aug. 3, 1959.

[103] Gerald M. Truszynski, "Space Communications," NASA pamphlet, 1963, 11; Mayer, interview, Houston, Oct. 19, 1964. Cf. Mayer, "The Motion of a Space Vehicle within the Earth-Moon System," in *Notes on Space Technology* (Langley, Va., May 1958). Memo, Mayer to Chief, Operations Div., "Trip Report of Visits to STL, Convair/Astronautics, Lockheed, and Stromberg-Carlson on Nov. 30, Dec. 1, through Dec. 4, 1959."

[104] John D. Hodge, interview, Houston, Aug. 11, 1964; David G. Simons, interview, San Antonio, April 24, 1964; Col. George M. Knauf was shortly to undertake the team training of Air Force medical monitors in the areas assigned to him at Patrick Air Force Base and at the Cape. See memo, Stanley C. White to Chief, Flight Systems Div., "Trip to USAF Surgeon General's Office . . . to discuss daily training of medical monitors with Colonel Knauf," Feb. 8, 1960. The STG also conducted medical monitor training at Langley.

[105] Sensitive security matters may be traced backward from various editions of NASA's "Mercury Program Security Classification Guide," SCG–9, the second and final revision of which was dated Dec. 15, 1964. The first of these guides, issued on Aug. 3, 1959, had only the particular command control code used for a specific flight designated at the highest level of security.

[106] The first network specifications, numbered S–45 dated May 21, 1959, were superseded by two revisions until S–45B of Oct. 30, 1959. Memo, Reid to all concerned, "Designation of Organization, Membership, and Operating Procedures for the Source-Selection Panel and the Technical Evaluation Board—Tracking and Ground Instrumentation, Project Mercury," June 12, 1959; memo, North to NASA Administrator, "Background of Project Mercury Schedules," with enclosure, Aug. 14, 1960, 4. The definitive contract with Western Electric, NAS 1–430, was not executed until Jan. 11, 1960, after which some 500 changes were processed before completion in June 1961. See the series of monthly "Progress Report to NASA: Project Mercury," Western Electric Company, Inc., Aug. 1959 to June 1961.

[107] Letter, Reid to Edmond C. Buckley, "Arrangements for Site Survey Teams in Connection with Tracking and Ground Instrumentation Systems for Project Mercury," July 16, 1959. For some indications of the extent of these difficulties, see (for Mexico) Purser, log for Gilruth, Aug. 17, 1959; and (for Africa) Ray W. Hooker, memo for files, "Tracking and Ground Instrumentation Systems for Project

Mercury, Special Report on African Sites," Oct. 20, 1959. See also "Report for the Cisler Committee on Tracking and Ground Instrumentation Systems for Project Mercury," NASA, Nov. 25, 1959.

[108] Arnold W. Frutkin, interview, Washington, Sept. 2, 1965; and Chaps. 1 and 2 of his book, *International Cooperation in Space* (Englewood Cliffs, N.J., 1965). For texts of all executive agreements, memoranda of understanding, and other international arrangements after 1959, see Senate Committee on Aeronautical and Space Sciences, 89 Cong., 1 sess., *United States International Space Programs*, July 30, 1965. Dwight D. Eisenhower, *The White House Years: Waging Peace, 1956–1961* (Garden City, N.Y., 1965), 344.

[109] Alfred Rosenthal, *The Early Years: Goddard Space Flight Center Historical Origins and Activities through December 1962* (Washington, 1964), 53, 57. Cf. "Fifth Anniversary, International Tracking of Space Vehicles," pamphlet, Goddard Space Flight Center, Greenbelt, Md., Jan. 31, 1963. Soulé interview.

[110] See anon., "The Manned Space Flight Tracking Network," pamphlet, NASA Goddard Space Flight Center, Greenbelt, Md., 1965. See also Loyd S. Swenson, Jr., "The Telecommunications Revolution in the Nineteenth Century," paper, American Studies Assn., Claremont, Calif., Nov. 1962.

[111] See Wilfred J. Mayo-Wells, "The Origins of Space Telemetry," in Emme, ed., *The History of Rocket Technology*, 253, 268. See also Harry L. Stiltz, ed., *Aerospace Telemetry* (Englewood Cliffs, N.J., 1961) and Mayer comments.

[112] John T. Mengel, comments, Sept. 14, 1965. Mengel (for the Navy), Edmond Buckley (for NACA), and Gerald De Bey (for the Army) had supported the Air Force studies for "Man-in-Space-Soonest" tracking requirements in 1958. See also Mengel, "Satellite Ground Data Networks," Appendix B in Alfred Rosenthal, *Goddard '63: A Year in Review at Goddard Space Flight Center* (Greenbelt, Md., 1964), B–1, B–9.

[113] M. S. Buist and G. M. Weinberg, "Real-Time Multi-Programming in Project Mercury," in Donald P. Le Galley, ed., *Ballistic Missile and Space Technology* (4 vols., New York, 1960), I, 436. See also J. Painter and E. Chicoine, eds., "Reference Notes on Communication Systems," NASA Manned Spacecraft Center, November 1962.

[114] The Burroughs and IBM computer systems at the Cape sent orbital insertion data by wire to the Goddard prediction computers, which then returned display data to the Mercury Control Center in milliseconds. For more adequate treatments, see Michael Chriss, "Establishment of NASA's Manned Tracking Network," NASA Historical Note HHN–54; Shirley Thomas, *Satellite Tracking Facilities: Their History and Operations* (New York, 1963); P. V. H. Weems et al., *Space Navigation Handbook*, NAVPERS 92988 (Washington, 1961). See also anon., "Mercury History: An Unclassified Documentation of the Contributions of Radio Command Guidance to Project Mercury," mimeographed 24-page document prepared by Information Services, General Electric, Radio Guidance Operation, Syracuse, N.Y., ca. June 1963.

[115] Powers, memo for file, "Points of Emphasis in Promoting the Public Picture of the Space Task Group," undated [ca. Dec. 1959].

## *Chapter VIII*

[1] Jacques Piccard, "Man's Deepest Dive," *National Geographic*, CXVIII (July 1960), 235; Edward L. Beach, "Triton Follows Magellan's Wake," *National Geographic*, CXVIII (Aug. 1960), 585–615; House Committee on Science and Astronautics, 86 Cong., 2 sess. (1960), *Ocean Sciences and National Security*, July 1, 1960; Norris and Ross McWhirter, eds., *Guinness Book of World Records* (paperback ed., New York, 1964), 205, 207; Bern Dibner, *The Victoria and the Triton* (Norwalk, Conn., 1962). On Jan. 23, 1960, a Pacific Fleet task element floated above the Marianas Trench, an abyssal canyon north of Guam, also known as the Challenger Deep, while Jacques Piccard, the son of Auguste who had designed the *Trieste*, and Donald Walsh, a Navy lieutenant, squeezed themselves into the bathyspherical gondola beneath their hydrostatic balloon. In this third of a series of dives, Piccard and Walsh sank down 7000 fathoms, or eight miles, where their vehicle endured 1085 tons of pressure per square foot and where they saw life on the bottom of the ocean. For all mankind, Piccard and Walsh figuratively "took possession of the abyss, the last extreme on our Earth that remained unconquered." Three months later, on April 25, 1960, the nuclear-powered submarine *Triton*, with 183 Americans captained by Edward L. Beach, completed the world's first undersea circumnavigation, following for two months submerged the wake of Magellan's ship, the *Victoria*, at an average speed of 18 knots for 41,519 miles. The inertial guidance

navigation system that made the trip of the *Triton* possible had grown out of the same research and development program, Project Navaho, that had provided the prototype rocket engine for the Redstone, Jupiter/Polaris, Thor, Atlas, and Titan.

[2] House Committee on Science and Astronautics, 86 Cong., 2 sess. (1960), *Hearings, Review of the Space Program* (Part 1, No. 3), testimony of T. Keith Glennan, 170, and *Project Mercury, First Interim Report*, Jan. 27, 1960; John W. Finney, "Soviet Space Man Held Pacific Aim," *New York Times*, Jan. 9, 1960; Finney, "U.S. Steps up Effort in Outer Space Race," *New York Times*, Jan. 19, 1960; Craig Lewis, "NASA's $802 Million Request May Grow," *Aviation Week*, LXXII (Jan. 25, 1960).

[3] Abe Silverstein, quoted in Albert Sehlstedt, Jr., "No Space Man Urgency Seen," Baltimore *Sun*, Jan. 26, 1960; William Hines, "Scientist Urges Use of Space for Humanity," Washington *Evening Star*, Jan. 25, 1960; Ralph E. Lapp, *Man and Space: The Next Decade* (New York, 1961), 55–67; Donald W. Cox, *The Space Race: From Sputnik to Apollo—and Beyond* (Philadelphia, 1962), 88–93; David Wise and Thomas B. Ross, *The U–2 Affair* (New York, 1962).

[4] See Frank H. Samonski, Jr., "Project Mercury Environmental Control System Technical History," MSC, Crew Systems Division report No. 63–34, Nov. 14, 1963, for a most thorough topical overview of this subject.

[5] Seymour Chapin, "The Pressurized Flight Industry in the Southwest Since 1930," paper, Pacific Coast Branch meeting, American Hist. Assn., Los Angeles, Aug. 26, 1964. See also Irwin Stambler, "Environmental System for Mercury Capsule is Simple, Rugged," *Space/Aeronautics*, XXXII (July 1959), 42–45.

[6] A. D. Catterson, interview, Houston, Oct. 23, 1964; memo, Stanley C. White, "Present Status—Major Systems: Environmental Systems," Feb. 1959; memo, Gerard J. Pesman to Tech. Assessment Committee, "Meeting with McDonnell Aircraft Corporation to Discuss Environmental Control System for the Manned Spacecraft Capsule," Jan. 23, 1959. Although STG decided this question in favor of the latter alternative in 1958, the possibility of a change existed throughout 1959. See also William K. Douglas comments, Aug. 17, 1965.

[7] Ms., Maxime A. Faget and Aleck C. Bond, "Technologies of Manned Space Systems," 55. For an excellent view of the controversy about mixed gas versus 100 percent oxygen systems, see Eugene B. Konecci, "Soviet Bioastronautics—1964," paper, National Space Club, Washington, D.C., Dec. 15, 1964. The Soviet choice of a near-sea-level environment was wise for several reasons, explained Konecci, but he added that the danger of decompression sickness may retard extravehicular operations and therefore "may prove to be the Achilles heel in their program."

[8] Edward H. Olling, interview, Houston, Sept. 14, 1965. See also Olling's Ms. paper, "Design Solutions and Test Results for the Life Support System for Project Mercury," Sept. 1960. Control of atmospheric dust and debris at the micron level was apparently first applied in the aerospace industry at the AiResearch factory in Los Angeles a few weeks before similar arrangements were made at the McDonnell plant in St. Louis.

[9] A. B. Thompson, "Physiological and Psychological Considerations for Manned Space Flight," Report E9R–12349, Rev., Chance Vought Aircraft Inc., Dallas, July 7, 1959, 165.

[10] Ms., John R. Barton, "Systems Engineering Considerations in Designing and Testing the Life Support System for Project Mercury," Oct. 14, 1960, 4.

[11] Minutes, Jack A. Prizzi, "Meeting with McDonnell—Environmental Control System—July 30, 1959, at Space Task Group," Aug. 17, 1959. Cf. memo, White to Chief, Flight Systems Div., "Approval of Specification Control Drawing No. 45–83700, Revision S," Aug. 7, 1959. Eventually capsule No. 7 was standardized on the ECS assumptions of 500 cc./min. oxygen consumption rate, 300 cc./min. cabin leakage rate, and 500 B.t.u./hr. body heating rate.

[12] Memos, Richard S. Johnston to Chief, Flight Systems Div., "Test Program—Environmental System Trainer," July 27, 1959; and "Report on Trip to ACEL to Discuss Installation of ECS Trainer in Altitude Chamber," Sept. 21, 1959; letter, Robert R. Gilruth to Chief, Bureau of Aeronautics, Dept. of the Navy, "Test Program for Environmental System Test Vessel," Sept. 28, 1959; memo, Charles D. Wheelwright to Chief, Flight Systems Div., "Trip Report," Sept. 29, 1959; Johnston, "Mercury Life Support Systems," paper, 28th annual meeting, Institute of Aeronautical Sciences, New York City, Jan. 25–27, 1960, 15.

[13] Memos, Samonski to Chief, Flight Systems Div., "Developments in the Environmental Control System Testing Program at McDonnell," June 13, 1960; and "Progress of Manned ECS Tests at MAC," July 25, 1960;

Ms., Johnston, "The Control and Measurement of the Mercury Capsule Environment," paper, Fifth National Symposium on Space Electronics and Telemetry, Washington, Sept. 19–21, 1960; J. A. Maloney and F. G. Richardson, "Test of a Life Support System under Simulated Operating Conditions," McDonnell Aircraft Corp., March 1, 1961, 21–23.

[14] Memo, White to Chief, Engineering and Contract Administration Div., "Project Mercury Full Pressure Suit Selection," Feb. 27, 1959. See also Frederick R. Ritzinger, Jr., and Ellis G. Aboud, "Pressure Suits—Their Evolution and Development," *Air University Review*, XVI (Jan.–Feb. 1965), 23–32.

[15] Edwin G. Vail and Charles C. Lutz, "Project Mercury Pressure Suit Evaluation," Wright Air Development Center, June 1959; Lee N. McMillion, interview, Houston, Nov. 1, 1963; "Agenda and Conclusion, Pressure Suit Evaluation Conference," STG, July 15, 1959. Cf. "Status Report No. 3 for Period Ending July 21, 1959," STG.

[16] William S. Augerson and McMillion, "Conclusions and Recommendations Concerning the Mercury Pressure Suit," Aug. 29, 1959; letter, STG to Langley Research Center, Attention Procurement Officer, "Project Mercury Pressure Suit Procurement," with enclosure, "Specification—Suit, Full Pressure, Project Mercury," Oct. 2, 1959. Cf. "Status Report No. 3."

[17] W. J. Berus, "Space Suits—Past, Present and Future," paper, spring meeting, Akron Rubber Group, April 4, 1963, 15. See also "Status Report No. 3." Ventilation oxygen entered the suit through a hose connection at the waist, was channeled through suit distribution ducts to body extremities, and flowed freely over the body back to the helmet.

[18] Memo, McMillion to Chief, Flight Systems Div., "Pressure Suit Status Report," Dec. 24, 1959.

[19] D. D. Ewing, "Sizing Problem on Project Mercury Pressure Suit," notes on proposed revision of Contract No. AS 60–8011C, Jan. 25, 1960; memo, McMillion, "Trip Report," March 1, 1960; memo, McMillion to Chief, Flight Systems Div., "Trip Report," June 3, 1960, with enclosure re decisions made in meeting at Goodrich plant, Akron, March 14, 1960. Cf. letter, Ewing to Carl F. Effler, "Report of Mercury Suit Meeting on June 1 and 2, 1960," June 7, 1960. "The complexity and difficulty of donning the full pressure suit was noted with covert satisfaction by the writer, 'an old-partial pressure suit man,'" said James P. Henry of STG in memo to Chief, Flight Systems Div., "Trip Report," May 6, 1960. Memo, McMillion to Faget, "Astronaut Comment on Pressure Suit," with enclosures, (1) agreements and (2) comments by astronauts, June 27, 1960.

[20] Certainly the most delicate of all such interfaces for the first few leaps into space was that between the biosensors and human skins. The issue of the rectal thermometer designed into the suit was accepted for the moment as a necessary intrusion. See memo, Wheelwright to Chief, Flight Systems Div., "Trip Report," March 1, 1960; letter, Warren J. North to Harold I. Johnson, "Comments on Johnsville Centrifuge Program," Nov. 23, 1960.

[21] Suit pressure was maintained by a demand regulator that metered the oxygen into the system. If cabin pressure failed, the demand regulator sensed the pressure loss, sealed the suit, and maintained it at 4.6 pounds. Should both systems fail—suit and cabin—there was an emergency oxygen valve that fed directly into the inlet hose at the waist junction. Before May 1961, the pressure suit had received 514 hours of manned testing.

Oxygen was metered into the cabin by a regulator to maintain a minimum limit of 5.1 pounds. In designed operation, the cabin system remained at ambient pressure on the pad and up to 27,000 feet. At that altitude it sealed off at 5.5 pounds. If there were a fire or a buildup of toxic gases, the astronaut could decompress the cabin manually, exhaust the toxic odors, and repressurize it. This system received 135 manned test hours at the Navy's Aviation Medical Acceleration Laboratory before May 3, 1961.

[22] Thompson, "Physiological and Psychological Considerations for Manned Space Flight," 4, 24, 47–49, 164. See also White, "Progress in Space Medicine," paper, Second World and Fourth European Congress for Aviation and Space Medicine," Rome, Oct. 27–31, 1959.

[23] D. G. Starkey, "Isolation," in "Physiological and Psychological Considerations for Manned Space Flight," 140–145. See also Philip Solomon, et al., "Sensory Deprivation, a Review," *American Journal of Psychology*, CXIV (Oct. 1957), 4.

[24] See, for example, Johnston, "Mercury Life Support System"; Faget and Robert O. Piland, "Mercury Capsule and Its Flight Systems"; and Bond and Alan B. Kehlet, "Review, Scope and Recent Results of Project Mercury Research and Development Program," papers,

28th annual meeting, Institute of the Aeronautical Sciences, New York City, Jan. 25, 1960.

[25] Charles W. Mathews, "Review of the Operational Plans for Mercury Orbital Mission," paper, 28th annual meeting, Institute of the Aeronautical Sciences, New York City, Jan. 25, 1960.

[26] Edward R. Jones, "Prediction of Man's Vision in and from the Mercury Capsule," paper, 31st annual meeting, Aerospace Medical Assn., Miami Beach, May 9, 1960.

[27] Jones, "Man's Performance in an Orbital Space Vehicle," paper, Iowa Academy of Science, University of Iowa, Iowa City, April 22, 1960, 7, 10.

[28] "Tentative Schedule of Activities for First Months of Training Program," STG, April–Oct., 1959.

[29] *Project Mercury: First Interim Report*, 54–59; "Astronauts: Symposium," *Life*, XLVII, Sept. 14, 1959; "Seven Brave Women Behind the Astronauts," *Life*, XLVII, Sept. 21, 1959; "Astronauts Get Their Prodigious Chariot," *Life*, XLVII, Dec. 14, 1959.

[30] Donald K. Slayton, "Like Seeing My Own Future," *Life*, XLVII, Feb. 29, 1960; M. Scott Carpenter, "Eerie World of Zero G," *Life*, XLVII, Mar. 21, 1960; Walter M. Schirra, Jr., "Suit Tailor-Made for Space," *Life*, XLIX, Aug. 1, 1960; L. Gordon Cooper, Jr., "First Rocket We Will Ride: Redstone's Role in Project Mercury," *Life*, XLIX, Oct. 3, 1960.

[31] Letters, Lila J. Phillips to Mercury Astronauts, July 21, 1959. Enclosed questionnaires were answered in part by each astronaut.

[32] Hugh L. Dryden, in interview, Washington, Aug. 31, 1965. Walter T. Bonney, in interview with Eugene M. Emme and William Putnam, Washington, Oct. 15, 1965, stressed the administrative need for one rather than seven such contracts, since NASA's modest public information staff was already deluged.

[33] Memo, North to Dir. of Space Flight Development, "Interim Status Report for Project Mercury," Aug. 7, 1959, 2; John A. Powers, interview, Houston, Nov. 12, 1965; Donald Slayton, interview, Houston, Dec. 16, 1964. For the contract made by DeOrsey on May 28, 1959, see House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *1962 NASA Authorization*, Part I, 147–148. Cf. William Hines, "Astronauts Face 'Exclusivity' Crisis," Washington *Evening Star*, Dec. 9, 1965. See also John Troan, "NASA Will Police Spacemen," *Washington Daily News*, April 4, 1962, for one account of another highly controversial issue, the offer of free homes in Houston.

[34] On NASA public information policy and the division of labor regarding public relations for Mercury between Headquarters and STG, see Walter Bonney's remarks before United Press International Editors' Conference, Washington, NASA release, Sept. 9, 1960. Bonney recalls the day "all hell broke loose!" (p. 4) and how astronaut information policy evolved. Many NASA officials still vigorously defend the propriety and the wisdom of the "personal stories" contracts, but others disagree. See also Walter T. Bonney, comments, Dec. 1, 1965.

[35] Memo, George C. Guthrie to Training Office, "Second Bimonthly Report," Aug. 10, 1959; memos, Stanley Faber to Project Dir., "Outline of the January Program on the Aviation Medical Acceleration Laboratory Centrifuge," Dec. 3, 1959; and "Additional Information on January Centrifuge Program," Dec. 15, 1959. Memo for files, Robert B. Voas, "Astronaut Activities During Missile Preparation, Launch and Flight, Preliminary Outline," Nov. 5, 1959.

[36] Letter, John H. Glenn, Jr., to James B Stockdale, Dec. 17, 1959. See also "Summary of Mercury-Johnsville Centrifuge Program of August 1959," NASA Project Mercury working paper No. 127, June 22, 1960.

[37] For a review article on the resonant frequencies of various bodily organs, see David E. Goldman, M.D., and Henning E. von Gierke, "The Effects of Shock and Vibration on Man," paper, Naval Medical Research Institute, Lecture and Review Series No. 60–3, Bethesda, Md., Jan. 8, 1960.

[38] Memo, William Douglas to Assoc. Dir., "Training, Static Firing of Jupiter with Mercury Capsule," Feb. 10, 1960; William H. Mayes and David A. Hilton, "External and Internal Noise of Capsules," paper, STG Research Dept. meeting, Feb. 1, 1960; letter, Charles J. Donlan to R. W. Costin, July 29, 1960. Even Congressional attention was invited to these problems by the publication of House Committee on Science and Astronautics, 86 Cong., 2 sess. (1960), *Noise: Its Effect on Man and Machine*, Oct. 13, 1960, 33–35.

[39] Memos, Alan B. Shepard, Jr., for files, "Report on Astronaut Training—Capsule Egress and Water Survival, Pensacola, Florida, Mar. 28–Apr. 1, 1960," April 5, 1960; and "Astronauts' Comments on Mercury Capsule Survival Kit and Equipment," April 28, 1960.

[40] Memo, Shepard to Project Dir., "Personal Parachute Application to Mercury," June 27, 1960. The results of these studies were summarized in memo, William C. Mosely, Jr., for Aleck Bond, "Procedure for Personal Parachute Usage During Mercury-Redstone Missions," April 18, 1961. On Project Excelsior, see Eugene M. Emme, *Aeronautics and Astronautics: An American Chronology of Science and Technology in the Exploration of Space, 1915–1960* (Washington, 1961), 114, 116, 120; Joseph W. Kittinger, "The Long, Lonely Leap," *National Geographic*, CXVIII (Dec. 1960), 854.

[41] "Highlights of the First Year of the Astronaut Training Program," with charts and tables for oral presentation, STG, May 1, 1960.

[42] See, e.g., "Briefing Given to NASA Astronauts," Rocketdyne BC1–59–12, Rocketdyne Div., North American Aviation, Inc., Canoga Park, Calif., Sept. 18, 1959.

[43] Johnson, "Pilots' Training Aids," briefing, Wright Air Development Center, Feb. 3, 1960, 2; letter, the astronauts to Dir., Project Mercury, Feb. 4, 1960.

[44] Robert R. Miller, interview (telephonic), Cleveland, Jan. 26, 1965. For an illustrated catalog of most United States training simulations of this nature, see H. E. von Gierke and E. Steinmetz, eds., *Motion Devices for Linear and Angular Oscillation and for Abrupt Acceleration Studies (Impact)*, NAS/NRC Publication 903 (Washington, 1961).

[45] James W. Useller, interview, Cleveland, May 1, 1964. See Useller and Joseph S. Algranti, "Pilot Reactions to High-Speed Rotations," *Aerospace* Magazine, XXXIV (June 1963), 501–504. Test subjects were brought up to speed in about 10–15 seconds, and then were expected to damp out all three axial rotations in the next 30 seconds or so.

[46] Useller interview. Meanwhile the Lewis altitude wind tunnel was being used as a space vacuum chamber and was needed for some important separation tests of the spacecraft from an Atlas adapter. R. R. Miller and Robert B. Nunemaker also ran tests of pyrotechnics, monitored by John B. Lee and Charles Yodzis of STG, that uncovered a host of anomalies in the design and performance of explosive bolts, retrograde and posigrade rockets, and the alignment of the escape rocket. See also souvenir picture booklet, "Astronaut Press Meeting, Lewis Research Center, March 4, 1960."

[47] "Status Report, Crew Training," April 1960, 3; see also memo, Brent Y. Creer and Rodney C. Wingrove to Dir., Ames Research Center, "Preliminary Results of Pilot's Sidearm Controller Tests Conducted on the AMAL–NADC Centrifuge . . .," Feb. 26, 1960.

[48] "Astronauts' Handbook—Project Mercury," preliminary edition, McDonnell Aircraft Corp., Jan. 25, 1960.

[49] "Project Mercury General Systems Document," NASA Project Mercury working paper No. 118, March 10, 1960, rev. Oct. 24, 1960, and March 23, 1961.

[50] Voas, "Human Factors Aspects of the Man-In-Space Program," paper, Air Force Scientific Advisory Board, Psychology and Social Science Panel, Jan. 26, 1961, 24, 7.

[51] Jones, "Analytical Techniques for Defining the Astronaut's Task," and "Astronauts' and Ground Station Failure Reference," papers, ninth annual Human Engineering Conference, Office of Naval Research, St. Louis, June 2, 1961.

[52] Voas, "Human Factors Aspects," 14; Jones, interview, St. Louis, Sept. 2, 1964; "The Failure Task Analysis," McDonnell Aircraft Corp., June 15, 1961, rev. June 21, 1962. Voas, for instance, believed, in spite of considerable opposition, that: "A rough estimate of the priority that should be given to each subsystem in the training program can be expressed as the reliability of the automatic component plus the estimated reliability for the human. Tasks associated with subsystems for where this sum is low should be assigned the highest priority in the training program. This procedure is similar to traditional task analysis procedures, but permits a more qualitative approach to the evaluation of design tradeoffs and the construction of training program."

[53] House Committee on Science and Astronautics, 86 Cong., 2 sess. (1960), *Hearings, Review of the Space Program*, testimony of George M. Low, Feb. 16, 1960, Part II, 761. See also Parts I and III for the overall presentation of a response to NASA's 10-year plan as discussed between Jan. 20 and Mar. 7, 1960. Cf. NASA, *Major Activities in the Programs of the National Aeronautics and Space Administration, October 1, 1959–March 31, 1960* [Third Semiannual Report to Congress], (Washington, 1960).

[54] Letter, Gilruth to Comdr., Air Force Ballistic Missile Div., Oct. 12, 1959; "Project Mercury Quarterly Report No. 5 for Period Ending Jan. 31, 1960," STG, Jan. 31, 1960. See also Leighton I. Davis, Maj. Gen., USAF, Operations Plan 60–1: *Department of Defense Support for Project Mercury*, AFMTC, May 31, 1960; cf. "Overall Plan Department

of Defense Support for Project Mercury Operations," AMR, Jan. 15, 1960.

[55] Sherwood L. Butler, "Monthly Status Report—Project Mercury," Oct. 2, 1959; "Monthly Status Report—Project Mercury," Nov. 3, 1959.

[56] J. E. Miller, "M–133 Elect. Coor. Tie-In Record," McDonnell Aircraft Corp., Jan. 6, 1960.

[57] Frank G. Morgan, Jr., "Summary of Capsule Coordination Meetings," McDonnell Aircraft Corp., Jan. 11, 12, 1960; message, Paul E. Purser to Logan T. MacMillan, Jan. 25, 1960.

[58] T. Keith Glennan, in House Committee on Appropriations, Special Subcommittee on Deficiencies, 86 Cong., 2 sess., Hearings, Feb. 1, 1960, *Supplemental National Aeronautics and Space Administration Appropriations 1960*, 2; cf. pp. 27 and 55.

[59] "Status Report No. 5," STG, 2. This status report continued on the next page with these significant remarks:

"It has also been found possible to make the configuration of the capsules for MR–2 . . . and MR–3 identical. The missions of these capsules remain unchanged. However, in order for the basic capsules to be identical, the quantities to be recorded for the primate carried in MR–2 must remain the same as those to be recorded for the man in MR–3. The advantage of making these capsules identical is that otherwise the first manned flight would have been in a capsule that differed in several respects from those that had been fired previously. Now there will be at least one firing of an identical capsule before inserting a man.

"The operations required for preparation and launch of the capsule have received very careful study, and it has been concluded that these operations will require much more time than was previously estimated. The resultant program with the delayed capsule deliveries was, however, felt to be unacceptable. For this reason, new, rather optimistic target times have been set for the checkout and launch period, and a study has been instituted to see whether these schedules can be met by careful planning of the work and facility utilization and by extra work shifts. The effects of all these factors are being considered in formulating a new schedule."

[60] Memo, Gilruth to staff, "Prospective Move of the Space Task Group to Goddard Space Flight Center, Beltsville, Maryland," Feb. 25, 1960; memo for files, William A. Herrnstein, Jr., "Work and Travel Performed by Langley Research Center Personnel in Support of Project Mercury," Oct. 6, 1960.

[61] "Anticipated Total Program Cost for Mercury Capsule," McDonnell Aircraft Corp., Jan. 14, 1960. Cf. "Contract NAS 5–59, Mercury Capsule Program—Financial Status Summary," with enclosures, McDonnell Aircraft Corp., May 31, 1960. C. F. Picard, McDonnell Aircraft Corp., Asst. Contract Manager, "Monthly Financial Report," Jan. 22, 1960, 2.

[62] R. O. Piland, interview, Houston, Nov. 5, 1964; memo, Gilruth to staff, "Advanced Vehicle Team," May 25, 1960; Joseph V. Piland, interview, Houston, Oct. 21, 1964.

[63] Memo, Gilruth to staff, "Changes in Organization of the Space Task Group," Jan. 11, 1960. See also Ms., Robert Merrifield and C. F. Bingman, "Organization: Technical History of Project Mercury," June 3, 1963.

[64] Memo for files, anon., "Outline of Off-Range Remote Site Training Program for Flight Control Personnel," Jan. 14, 1960. Cf. "Aeromedical Flight Controller Briefing," NASA/STG, May 23–27, 1960. "Operation and Maintenance: Flight Controller Remote Sites: Operation Manual, MO–118R," Western Electric Co., June 1960.

[65] Letter, Walter C. Williams to Kurt H. Debus, "Proposal for Mercury-Redstone Coordination Committee," Jan. 18, 1960; letter, Williams to Donald N. Yates, "Mercury-Atlas Flight Test Working Group," Jan. 18, 1960; Howard Gibbons, "Ostrander's Job at NASA Not Related to Space Rift," Newport News *Daily Press*, Dec. 10, 1959. See also proposed memo of understanding, "Relationships Between OSFP and OLVP Groups at AMR," submitted to Ostrander and Silverstein April 29, 1960.

[66] Memos, Williams to staff, "Responsibilities of Mercury Launch Coordination Office," Feb. 11, 1960; "Organization for Mercury Field Operations," Feb. 12, 1960; letter, Williams to Yates, "Position Titles for Operation of Project Mercury," March 9, 1960; letter, Williams to Cdr., DesFlotFour, "Test Objectives and Recovery Requirements for the Project Mercury Atlas Test One," March 15, 1960, with enclosure. The aborted "Launch Operation Manual for Project Mercury," compiled by Dugald O. Black, A. M. Busch, A. M. Eiband, John Janokaitis, Jr., and approved by Scott H. Simpkinson, B. Porter Brown, and G. Merritt Preston at the Cape in March 1960 is a rare but invaluable guide to its

subject at this time.

[67] Memo, William M. Bland, Jr., to Chief, Flight Systems Div., "Division Participation in Project Mercury," March 4, 1960. For an overview of the increasing tempo of Mercury operations at the Cape, see memo, Martin A. Byrnes for Assoc. Director, "Administrative Support for the STG Facilities at Cape Canaveral," March 4, 1960; and C. Frederick Matthews for staff, "Administrative Staff for Mercury Field Operation Organization," May 9, 1960.

[68] Minutes, "Mercury Network Meeting," NASA/STG, Feb. 9, 1960; memo, Gilruth to Div. Chiefs, "Designation of Flight Controllers for Mercury Flight Operations," Feb. 8, 1960; memo, C. F. Matthews to all concerned, "Mercury Flight Controller Personnel Indoctrination and Training Plan Presentation," Feb. 25, 1960; Williams, interview, Houston, Aug. 23, 1965. See also Jim W. McCommis, draft Ms., "Flight Control Operations," for Mercury Technical History, Nov. 19, 1963.

[69] Memo, William W. Petynia to Chief, Flight Systems Div., "Summary Report of the Duties and Responsibilities of the STG Project Engineer During Capsule No. 1 CST," March 16, 1960. For the best overview of the status of the program as seen by the STG managers at the end of this period, see memo for files, Purser, "Additional Background Material on Project Mercury," May 11, 1960; cf. Purser's similar memo, "General Background Material on Project Mercury," March 23, 1959.

[70] See R. I. Johnson, et al., "The Mercury-Redstone Project," TMX53107, MSFC Saturn/Apollo Systems Office, June 1964, 5–39, 41; Ms., "Proceedings of the Mercury-Atlas Booster Reliability Workshop," Convair/Astronautics, San Diego, July 12, 1963, passim. See also ABMA/AOMC instructions, N. I. Reiter, Jr., "Mercury Project Symbol," Oct. 7, 1959, Code AP 940–13, ORDAB–DY.

[71] Bernhard A. Hohmann, "Pilot Safety and Quality Assurance for Project Mercury," report No. STL–TR–60–0000–69047, Feb. 8, 1960; [Kucheman, Henry B.], "Reference File, AFBMD Support, Project Mercury," bound folder of documents, Air Force Space Systems Div., El Segundo, Calif., Jan. 4, 1961, Sect. 5, Table 11; Osmond J. Ritland, interview, Andrews Air Force Base, Md., Dec. 30, 1964.

[72] Hohmann interviews; see p. 189. See also Simpkinson, interview, Houston, Oct. 4, 1965, and papers from the period between June 1961 and May 1962 when he was assigned to San Diego as Gilruth's special assistant. For more technical details, see R. J. Smith, "Flight Proofing Test Report for Abort Sensing and Control Unit—Mercury—Missile-borne," Convair/Astronautics report No. 27A515 R, Aug. 5, 1960.

[73] "Reliability Program Review—Project Mercury," McDonnell Aircraft Corp., Feb. 27, 1960; John C. French, interview, Houston, Aug. 3, 1964. For a retrospective view of reliability in all of the Mercury program, see Walter C. Williams, "On Murphy's Law," in Paul Horowitz, ed., *Manned Space Reliability Symposium,* Vol. I, American Astronautical Society Science and Technology Series (New York, 1964), 1–11.

[74] Purser, log for Gilruth, Jan. 6, 1960; Richard M. Mansfield, "Project Mercury Revisited," *Virginian-Pilot and Portsmouth Star,* March 27, 1960; House Committee on Science and Astronautics, 86 Cong., 2 sess. (1960), *Life Sciences and Space,* Aug. 15, 1960, 13; Senate Committee on Aeronautical and Space Sciences, 86 Cong., 2 sess. (1960), *Space Research in the Life Sciences.* At this juncture, Astronauts Shepard and Grissom were asking for permission to ride the next Little Joe shot into space. Virgil I. Grissom, interview, Houston, March 29, 1965.

[75] Purser, log for Gilruth, Feb. 9, 1960. See also Robert L. Seat, interview, St. Louis, Sept. 1, 1964; Seat and Waldram, "Project Mercury Test Plan," McDonnell Aircraft Corp., Feb. 19, 1959.

[76] Purser, log for Gilruth with enclosures, agenda for conferences on reliability test program, March 9, 1960. Two other Chrysler Corp. engineering executives responsible for factory management of man-rating the Redstone were Robert P. Erickson and Edward J. Dofter: H. D. Lowrey, interview, Washington, Nov. 17, 1965. For details of the factory test programs see R. M. Torigian, "Reliability Test of the Redstone A–7–1 Rocket Engine, RE 7112a," Chrysler Corp. Missile Division Technical Memorandum ML–M125, April 14, 1960; and G. S. Upton, "Mercury-Redstone Aft Section Test Report," CCMD Technical Report GLC–R5, Oct. 1960.

[77] Walter F. Burke, interview, Aug. 31, 1964; MacMillan, interview, St. Louis, Sept. 1, 1964. See also minutes, Jerome B. Hammack and Jack C. Heberlig, "ABMA–MAC–NASA Panel No. 1 Meeting," March 22, 1960; memo, Curtis L. Ferrell to Emil P. Bertram, MFL, "Mercury-Redstone [capsule-booster documen-

tation problem]," May 18, 1960.

[78] James A. Chamberlin, interview, Houston, June 1, 1964; and comments, Sept. 9, 1965. See also memo, Gilruth for all organizational units, "Organization of NASA Participation in CST at MAC," May 12, 1960.

[79] Memo, Silverstein to Dir., Marshall Space Flight Center, "Mercury Capsule Prelaunch Operations at Huntsville," March 29, 1960. A recent revision of ABMA's checkout plans had not shown much effort to save time. See "Mercury Checkout at Systems Analysis and Reliability Laboratory," ABMA-DOD Report No. DRT-TM-5-59, Aug. 13, 1959, Rev. A, March 5, 1960.

[80] Memo, Silverstein to Dir., Marshall Space Flight Center, "Review of Mercury Capsule Prelaunch Operations at Huntsville," April 5, 1960; House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *Defense Space Interests, Hearings*, statement and documents, General Thomas D. White, USAF, 91–97.

[81] Purser, "Notes on Manned Space Flight Management Meeting, June 27–28, 1961," 1, 2. See also Gilruth memo, "Organization of NASA Participation in CST."

[82] Memo, Robert E. McKann to Chief, Flight Systems Div., "Visit to STL, CV/A, and Rocketdyne (NAA) Feb. 15–18, 1960," Feb. 29, 1960. See also P. I. Harr, "Results of Reliability Evaluation Test Program for Mercury-Atlas Abort Sensing and Implementation System," Convair/Astronautics report No. AX62-0008, April 24, 1962.

[83] Memo, Edison M. Fields to Chief, Flight Systems Div., "Visit to BMD/STL at Los Angeles," Jan. 19, 1960; letter, Hohmann to Gilruth, March 25, 1960; letter, Williams to Hohmann, April 18, 1960; *Convariety*, Feb. 17, 1960. See also transcript, "Proceedings of the Mercury-Atlas Booster Reliability Workshop," San Diego, July 12, 1963, passim. The reliability team at Convair/Astronautics consisted of factory manager J. P. Hopman, reliability chief H. F. Eppenstein, and quality control manager D. R. Archibald. For similar concerns on the Redstone, see memos, Debus to Earl M. Butler, "Weight and Balance Measurements on Project Mercury," Dec. 23, 1959; and H. R. Palaoro to Butler, "Weight and Balance Measurement Requirements for Project Mercury-Redstone," Feb. 16, 1960.

[84] "Status Report No. 6 for Period Ending April 30, 1960," STG; "MA-1 Report No. 3 for Period Ending Jan. 27, 1960," STG; "MA-1 Report No. 4 for Period Ending Feb. 3, 1960," STG; "MA-1 Report No. 5 for Period Ending Feb. 4, 1960," STG; "MA-1 Report No. 10 for Period Ending April 15, 1960," STG; memo, Bond to Chief, Engineering Div., "MA-1 Test Flight," Feb. 1, 1960.

[85] Memo, North to Dir., Space Flight Programs, "Request for Approval of Mercury Funding," June 24, 1960. See also Evert Clark, "NASA Centralizes Launch Management," *Aviation Week*, LXXII (May 30, 1960), 28, 29.

[86] See Robert L. Rosholt, *An Administrative History of NASA, 1958–1963*, NASA SP-4101 (Washington, 1966), 154–160; memo, T. Keith Glennan to Dir., "Appraisal of NASA's Contractor Policy and Industrial Relations," Feb. 29, 1960. For an excellent overview of NASA policies in general at this time, see the typescript, "Questions and Answers proposed for Congressional Testimony," by Hugh L. Dryden's staff, ca. May 1960.

[87] "Information Requested by McKinsey and Co., Inc.," STG, April 9, 1960; letter, Gilruth to Harry J. Goett, Dir., Goddard Space Flight Center, May 3, 1960.

[88] Rosholt, *Administrative History of NASA*, 154, 101, 124; Rosholt has paraphrased the McKinsey report as follows (pp. 157–158):

"The report revealed that NASA's record in supervising its out-of-house efforts was spotty. Difficulties had arisen because NASA neglected certain basic prerequisites to effective contractor supervision, such as adequate statements of work, sufficient and flexible funding, and properly focused technical responsibility. (A basic problem in connection with the last named prerequisite was NASA's tendency to establish two channels of supervision—one from headquarters, the other from the field center.)

"NASA's supervisory job was difficult in that it could neither use the 'trust the contractor' approach (high reliability was too crucial to be left to the contractor alone) nor the 'tight control' approach (which would 'discourage contractor creativity and initiative'). . . . Therefore NASA had to follow a middle course, which combined contractor operating freedom with close NASA guidance. To achieve this balance it would be essential that there be a constant flow of information back and forth between NASA and the contractor. This flow could be promoted by periodic progress review meetings between NASA and the contractor, the placement of a NASA representative in the contractor's plant (to permit continuous face to face communication), and the use of a progress reporting system."

[88] "Pretest Report for Off-the-Pad Escape System Qualification Test," NASA Project Mercury working paper No. 112, March 1, 1960.

[89] See "Determination of Net Thrust of Project Mercury Tower Jettison Rocket and Escape Tower Assembly," NASA Project Mercury working paper No. 202, July 3, 1961; "Review of Mercury Launch Abort System Experience . . .," NASA general working paper No. 10,007, July 15, 1963.

[91] Memo, Bland for Flight System Division files, "Program Objectives," Sept. 30, 1959, 2.

[92] House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *A Chronology of Missile and Astronautic Events,* March 8, 1961, 114, 115. See also Charles S. Sheldon II, "The Challenge of International Competition," paper, third American Inst. of Aeronautics and Astronautics/NASA Manned Space Flight Meeting, Houston, Nov. 6, 1964, 10–11, reprinted and revised as Appendix A in Senate Committee on Aeronautical and Space Sciences, 89 Cong., 1 sess. (1965), *International Cooperation and Organization for Outer Space,* 427–477.

## *Chapter IX*

[1] Memos, George M. Low to Abe Silverstein, "Information for Program Management Plan Meeting," Oct. 6, 1960; T. Keith Glennan to Silverstein, July 11, 1960; Silverstein to Glennan, "MR–3 Launch Date," July 16, 1960; Silverstein to Robert R. Gilruth, "MR–3 Launch Schedule," July 25, 1960; Walter C. Williams to NASA Hq., International Programs Office, "Monthly Summary of Project Mercury Activities," Aug. 8, 1960; Warren J. North, "History of Mercury Schedules: Earliest Possible Manned Flights," chart, Aug. 13, 1960. See also Abe Silverstein, "Progress in Space Flight," *Astronautics,* V (Nov. 1960), 24–25, 140–142.

[2] For the Report of the President's Commission on National Goals, see Henry M. Wriston, et al., *Goals for Americans* (Englewood Cliffs, N.J., 1960). Note especially the section by Warren Weaver, pp. 101–124, on "A Great Age for Science." Cf. J. L. Penick, Jr., et al., eds., *The Politics of American Science: 1939 to the Present* (Chicago, 1965), 221.

[3] House Subcommittee of the Committee on Appropriations, 86 Cong., 1 sess. (1959), *National Aeronautics and Space Administration Appropriations,* testimony of Hugh L. Dryden, 15; House Committee on Science and Astronautics, 86 Cong., 2 sess. (1960), *Review of the Space Program,* Part II, testimony of George M. Low, Feb. 16, 1960, 761. For an excellent analysis of political positions and public opinion on American space policy (1957–1963) as a whole, see Vernon Van Dyke, *Pride and Power: The Rationale of the Space Program* (Urbana, Ill., 1964). Eisenhower's position is described on pp. 82–83.

[4] Glennan's introspection on the role of international competition was best expressed in an address at a Yale University symposium on Oct. 7, 1960. See also letter, Glennan to Eugene M. Emme, Oct. 19, 1965. For an overview of Air Force programs, see Ernest G. Schwiebert, "USAF's Ballistic Missiles—1954–1964: A Concise History," *Air Force and Space Digest,* XLVII (May 1964), 51–166, later published as *A History of the U.S. Air Force Ballistic Missiles* (New York, 1965).

[5] The best open monograph comparing Soviet and American space accomplishments is Charles S. Sheldon II, "The Challenge of International Competition," paper, third American Inst. of Aeronautics and Astronautics/NASA Manned Space Flight Meeting, Houston, Nov. 6, 1964, revised and reprinted in Senate Committee on Aeronautical and Space Sciences, 89 Cong., 1 sess. (1965), *International Cooperation and Organization for Outer Space,* Appendix A, 427–477.

[6] "Project Mercury Discussion," brochure, STG, June 20, 1960. See also memo, Dieter Grau to Dir., Guidance and Control Div., Marshall Space Flight Center, "Unsatisfactory Condition on MR Abort Sensing System," Oct. 11, 1960; minutes, "Resume of Mercury-Redstone Panel 2 Meeting," LOD–MSFC, Aug. 24, 1960.

[7] "Project Mercury Discussion," B–276, B–187, B–258, B–204; comments, William Underwood, Executive Sec. of CMLC, to Eugene M. Emme, Nov. 1, 1965; draft Ms., B. Leon Hodge, et al., "Recovery Operations Portion," for Mercury Technical History, Aug. 1963.

[8] NASA Contract No. NAS–190, "Reliability Study of Mercury Capsule System," June 9, 1960, was signed by William P. Kelly, Jr., for the government and by D. P. Murray for McDonnell Aircraft Corp.

[9] Nicholas E. Golovin, "An Approach to a Reliability Prediction Program," American Society for Quality Control. *Transactions of 1960 Convention,* San Francisco, May 25,

1960, 173. See also, memos, Silverstein to Deputy Assoc. Administrator, "Project Mercury Reliability Analysis," June 21, 1960; Golovin to Dir., Office of Space Flight Programs, "Project Mercury Reliability," June 23, 1960. "Old data and wrong ground rules gave bad figures from our standpoint," said Walter Williams in interview, Houston, Aug. 23, 1965. Silverstein and Low tended to side with the working levels on this issue: see Low, comments, Oct. 5, 1965.

[10] Letter, Glennan to James S. McDonnell, Jr., June 30, 1960, with enclosure [from which next quotation is taken], "Proposed Work Statements for McDonnell on Mercury Capsule System Reliability," June 30, 1960, 2.

[11] Letter, McDonnell to Glennan, July 13, 1960, NASA Central Files, Washington. Apparently Mr. McDonnell was unaware of the NASA–MAC reliability contract NAS–190.

[12] Paul E. Purser, log for Gilruth, July 21, 1960; "Informal Reliability Discussion for STG by AAR Staff," July 21, 1960; Ms. notes on reliability meeting, Purser, July 21, 1960; F. John Bailey, Jr., interview, Houston, July 16, 1964. For a later statement of Headquarters' policy see Landis S. Gephart, "NASA Requirements for Reliability and Quality Assurance," in *Western Space Age Industries and Engineering Exposition and Conference: NASA Day, April 27, 1962,* NASA SP–4 (Washington, 1962), 49–56.

[13] John C. French, interview, Houston, Aug. 3, 1964; memo, Gephart to Everett W. Quintrell, "Background Information on Astronaut's Task Description and Performance Evaluation," Aug. 31, 1960. Cf. letter, J. Y. Brown, Contract Manager, McDonnell Aircraft Corp., to W. P. Kelly, Jr., NASA Contracting Officer, Aug. 24, 1960.

[14] See Low, comments, Oct. 5, 1965; Aleck C. Bond and Maxime A. Faget, Ms., "Technologies of Manned Space Systems," Chap. 14, "The Role of Ground Testing in Manned Spacecraft Programs," 167–177.

[15] Mercury operations were governed by the agreement "Overall Plan—Department of Defense Support for Project Mercury Operations," Jan. 15, 1960, but some of the difficulties in working out specific operational procedures at the Cape may be found in Francis E. Jarrett, Jr., and Robert A. Lindemann, "Historical Origins of NASA's Launch Operations Center," Kennedy Space Center, Historical Monograph No. 1, Cocoa Beach, Fla., Oct. 1964, 69–76. See also letters, Henry N. Moore to distribution, AFMTC, "NASA Organizational Changes at AMR and PMR," June 27, 1960; and Kurt H. Debus to G. J. Weber, MAC, July 28, 1960; and Ms. paper, anonymous, "Responsibilities and Procedures for AMR Support of Project Mercury," ca. Aug. 1, 1960.

[16] J. F. Shields, personnel study chart, MSC Florida Operations, Jan. 4, 1964; G. Merritt Preston, interview, Cape Kennedy, April 29, 1964; George F. Killmer, Jr., interview, Houston, Sept. 14, 1965. See also Ms. paper, Gilbert B. North, "Development and Checkout of the NASA Mercury Capsule," McDonnell Aircraft Corp. [ca. Sept. 1960].

[17] John F. Yardley, William Dubusker, interviews, St. Louis, Aug. 31, Sept. 1, 1964. See also Ms. paper, H. H. Leutjen, "Ground Checkout and Launch Procedures for Man-in-Space Operations," McDonnell Aircraft Corp. [ca. Aug. 1961]; McDonnell Aircraft Corp. interoffice memo, J. T. Dale to W. F. Burke, "Mercury-Redstone Panel I Meeting at MSFC on 11 August 1960," Aug. 16, 1960. Field procurement was standardized to some extent by memo, Harold G. Collins to all Mercury Hangar S personnel, "Procurement Procedures on Contract NAS 5–59," Sept. 8, 1960.

[18] Project Orbit is not to be confused with Project Orbiter; see p. 29. Yardley, Robert L. Seat, interviews, St. Louis, Sept. 1, 1964; memo, Lewis R. Fisher for Project Director, "Proposal for Environmental Qualification Test of Mercury Capsule," June 21, 1960; A. E. Wilkes, "Proposal for Full Scale Simulated Mission Test, Orbit Phase; Immediate Capabilities," McDonnell Aircraft Corp. report No. 7730, Aug. 29, 1960; memo, Floyd W. Fults to distribution, "Project Orbit Team Member's Responsibilities," McDonnell Aircraft Corp. memo No. PO–650–3, Feb. 2, 1961. For an overview of Project Orbit, see A. M. Paolini, "Evaluation of a Mercury Spacecraft in a Simulated Orbit Environment," McDonnell Aircraft Corp. preliminary report, May 29, 1962.

[19] Gilruth quoted by John J. Williams and Donald M. Corcoran, "Mercury Spacecraft Pre-Launch Preparations at the Launch Site," paper, American Institute of Aeronautics and Astronautics, Space Flight Testing Conference, Cocoa Beach, Fla., March 18–20, 1963, 18. Cf. p. 28. See also draft Ms., Frank M. Crichton, "Quality Control and Inspection," for Project Mercury Technical History, July 3, 1963.

[20] Bond and Faget, "Technologies of Manned Space Systems"; *Development Engineering Inspection Data Book,* SEDR 183, Mc-

Donnell Aircraft Corp., Aug. 16, 1960. For Project Orbit, see F. W. Fultz, A. E. Wilkis, J. J. Mazzoni, et al., informal McDonnell Aircraft Corp. memos, Sept. through Dec. 1960, including preliminary McDonnell report 7869–9 [no title], June 7, 1961: all included in file by Robert A. Hermann and Joe W. Dodson, "Project Orbit notes."

[21] Bailey interview; Mss., "Briefings, NASA-Industry Apollo Technical Conference," July 18, 1961; "Reliability and Flight Safety Problems," April 4, 1962, 8; "Reliability and Crew Safety in Manned Space Flight," Feb. 20, 1963; Bailey, "Review of Lessons Learned in the Mercury Program Relative to Spacecraft Design and Operations," paper, American Institute of Aeronautics and Astronautics Space Flight Testing Conference, Cocoa Beach, Fla., March 18, 1963.

[22] Abe Silverstein, interview, Cleveland, May 1, 1964; House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *Fourth Semiannual Report of the National Aeronautics and Space Administration,* 208–209.

[23] Ms., Karl F. Greil, for Mercury Tech. History, "History of the Reaction Control System," July 1962, 160–161. Cf. 145, 67–68 [English trans. by L. S. S.]. See also another draft Ms. by Norman B. Farmer, "Instrumentation," June 27, 1963, for some discussion of equally acute problems.

[24] See R. D. Korando, "Mercury Capsule No. 7: Configuration Specification (Mercury-Redstone No. 3)," Report 603–7, McDonnell Aircraft Corp., Aug. 1, 1960, revised Nov. 10, 1960; R. F. Mackey, "General Flight Plan: Atlas Boosters for Project Mercury," Aerospace Corp. report AS–60–0000–0036, Sept. 1960.

[25] Memo, Faget to Flight Systems Div., "Mercury-Atlas Meeting on Feb. 26, 1960 at Space Technology Laboratories," March 4, 1960, 3.

[26] NASA News Release 60–233, "MA–1 Capsule Instrumentation," undated; memo, Charles J. Donlan to Langley Research Center, attention Clyde Thiele, "Inspection of MA–1 Capsule," March 18, 1960; memo, R. E. McKann to Chief, Flight Systems Div., "Trip to Mercury Project Office at Patrick Air Force Base," April 14, 1960. The basic preflight documentation for MA–1 is found in the following NASA Project Mercury working papers: "MA–1 Mission Directive," No. 132, April 11, 1960; "General Information for MA–1 Recovery Force," No. 142, July 8, 1960; "Landing Area Prediction MA–1," No. 143, July 13, 1960; "Summary of Calculated Preflight Trajectory Data for MA–1," No. 144, July 25, 1960. See also "Data Acquisition Plan, MA–1," undated; and "Project Mercury Description of Plans for MA–1," prelaunch report, June 24, 1960.

[27] Letter, Walter Williams to Cdr., DesFlotFour, March 15, 1960, with enclosure, "Test Objectives and Recovery Requirements for the Project Mercury Atlas Test One."

[28] Detailed descriptions of preflight operations for all Mercury launches are summarized in Ms., George F. Killmer, Jr., et al., "Mercury Technical History—Preflight Operations," MSC Florida Operations, Dec. 30, 1963. For MA–1, see pp. 68–71. For an overview of the coordination and cooperation mechanics among the Mercury-Atlas team, see letters, Silverstein to Courtland D. Perkins, Asst. Secy. of the Air Force (R and D), Aug. 26, 1960, and Gilruth to Silverstein, "Project Mercury Coordination between NASA–MAC and BMD–STL–Convair," Aug. 26, 1960, with enclosures.

[29] Memo, Low to Administrator, "Mercury-Atlas Test No. 1," July 26, 1960. For the more general "man-rating" procedures for the Atlas Booster about this time, see STL report TR–60–0000–69079, "Atlas Booster Flight Safety Review General Operating Procedures and Organization," June 6, 1960.

[30] Memo, Low to Administrator, "Mercury-Atlas 1, Post-Launch Information," July 29, 1960; see also Ms., "MA–1 Operation, 7/29/60," launch diary, anon. This same day George Low delivered a paper before the first NASA-Industry Conference that officially and publicly named for the first time "Project Apollo" as a manned lunar circumnavigation program for the future: see *NASA-Industry Program Plans Conference,* Washington, D.C., July 28–29, 1960, 80.

[31] Memo, North to Administrator, "Analysis of MA–1 Malfunction," Aug. 22, 1960. See also Sally Anderson, ed., *Final Report Mercury/Atlas Launch Vehicle Program,* Aerospace Corp. report No. TDR–269 (4101)–3, El Segundo, Calif., Nov. 1963, VIII–14.

[32] Joseph A. Kies, Naval Research Laboratory, Washington, "Atlas-Mercury Failure: Examination of Failed Parts," report, Aug. 30, 1960, 3; Andre J. Meyer, Jr., "Trip Report," Aug. 30, 1960.

[33] "Flight Test Report for Mercury-Atlas Mission No. 1 (capsule No. 4)," NASA Project Mercury working paper No. 159, Nov. 4,

1960, 12–1. Some idea of the complexity of data reduction procedures for Mercury in general and of the impact of MA–1 on data coordination procedures in particular may be gleaned from the draft Ms. by Richard G. Arbic and Robert C. Shirley, "Data Coordination," for Mercury Technical History, Part III, M., July 10, 1963.

[34] Minutes, "Mercury-Atlas Coordination Panel, Sept. 14, 1960," Sigurd A. Sjoberg, secretary, with enclosures, Sept. 29, 1960.

[35] Transcript, "Press Group Interview with Gilruth, Williams," Oct. 26, 1960, 2. Leading questions were asked by Douglas Dederer of the *Cocoa* (Fla.) *Tribune*. Gilruth also was reported to have said that he would not be surprised "to wake up any morning" to find the Soviets had accomplished manned orbital flight. Alvin B. Webb, Jr., *Washington Post*, Oct. 30, 1960. Webb also editorialized to say, "Mercury—named for a winged-footed Roman God—appears to have both feet in a molasses vat." House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *A Chronology of Missile and Astronautic Events*, 123, 124, 132; Sheldon, "The Challenge of International Competition," passim.

[36] For an overview of the parallel development of this rocket research aircraft see Thomas A. Toll and Jack Fischel, "The X–15 Project: Results and Research," *Astronautics and Aeronautics*, II (March 1960), 20–28.

[37] Eugene M. Emme, *Aeronautics and Astronautics: An American Chronology of Science and Technology in the Exploration of Space, 1915–1960* (Washington, 1961), 126–130.

[38] *Public Papers of the Presidents of the United States: Dwight D. Eisenhower, 1960–61* (Washington, 1961), 630; *A Chronology of Missile and Astronautic Events*, 121, 123. See also Senate Committee on Aeronautical and Space Sciences, 88 Cong., 1 sess. (1963), *Documents on International Aspects of the Exploration and Use of Outer Space, 1954–1962*, May 9, 1963, 181. Eisenhower listed *Pioneer V, Tiros I, Transit 1, Echo 1* and the X–15 flight in the "impressive array of successful experiments" during the year preceding Aug. 17, 1960. He omitted mention of the first successful Polaris launches from the submerged nuclear submarine *George Washington*, on July 20, for flights of over 1000 miles down the Atlantic Missile Range, and he also avoided publicizing the solid-fueled Minuteman missile and the SAMOS and MIDAS satellite programs.

[39] *Washington Post*, Sept. 27, 1960. Chapman Pincher reported in the *Washington Daily News*, Dec. 1, 1960, that Victor Jaanimets, a sailor who deserted the Russian ship that brought Khrushchev to New York, had told U.S. intelligence services that the ship, the *Baltika*, was equipped with mockups and demonstration equipment to advertise the Soviet feat in case they succeeded in an early attempt to put a cosmonaut in orbit.

[40] *A Chronology of Missile and Astronautic Events*, 129. See also Nancy T. Gamarra, "International Aeronautical Federation (FAI)," section in Senate Committee on Aeronautical and Space Sciences, 89 Cong., 1 sess. (1965), *International Cooperation and Organization for Outer Space*, 419–426.

[41] Silverstein quoted in news story in Newport News *Times-Herald*, Aug. 8, 1960. See also Brig. Gen. Thomas R. Phillips, "U.S. Out of Man-in-Space Race Until Saturn Is Ready in 1965," and "Criticism of Mercury Space Program Said to Lack Validity," *St. Louis Post-Dispatch*, Sept. 1 and 2, 1960; "Astronauts Hope for '61 Flight," *New York Times*, Sept. 19, 1960; "NASA's Chief Expects Red Space Shows," Baltimore *Sun*, Sept. 20, 1960; Warren Rogers, Jr., "Man-in-Space Effort by U.S. Rolls Again," *New York Herald Tribune*, Sept. 25, 1960.

[42] *Newsweek*, LIV (Oct. 19, 1959), 73–76. This magazine continued with blanket criticisms in LIV (Nov. 2, 1959), 26; LV (Feb. 8, 1960), 67–68; LV (Feb. 15, 1960), 35; but a special report on the manned space race in *Newsweek*, LVI (July 11, 1960), 55–59, was entitled "The Dawn," symbolizing better understanding of STG's efforts.

[43] Hanson W. Baldwin, "Neglected Factor in the Space Race," *New York Times Magazine*, Jan. 17, 1960, 77; Arthur C. Clarke, "Rocket to the Renaissance," *Playboy*, VII (July 1960), 34, 84.

[44] James Barr, "Is Mercury Program Headed for Disaster?" *Missiles and Rockets*, VII (Aug. 15, 1960), 12–14. See also Carl R. Huss, comments, Oct. 5, 1965.

[45] Memo, Gilruth to staff, "Favorable Press Comments (for a change)," with two enclosures, Sept. 16, 1960: Marvin Miles' article described the "recent splurge of sniping at the Mercury program," and Glennan's letter of August 26 commended the article "as a shot of adrenalin" for all the workers on Mercury.

[46] Memo, North to Administrator, "Background of Project Mercury Schedules," with

enclosures, including a chronology, Aug. 14, 1960. Significant excerpts from this memo illustrated other features of Headquarters concerns:

"A major factor in the compressed Mercury schedule is concurrent effort in the areas of research and development, design, and manufacturing. As a result of this concurrent effort, many of the capsule subcontractors underestimated their costs and delivery dates. As early as October 1959, McDonnell anticipated cost increases ranging from 200% to 450% from some of their major subcontractors, such as Bell Aircraft, AiResearch, Collins Radio, and Grand Central Rocket.

"Because of different flight test objectives, it is possible to fly some of the early capsules with incomplete and unqualified systems.

"From the standpoint of project urgency, it was consistent policy to set . . . classified target schedules as tight as possible. . . . However, since problem areas cannot be pinpointed in advance, it was felt that the project objectives could be most rapidly achieved by purposely setting optimistic target schedules and keeping everyone working to meet these dates. . . .

"One is tempted to extrapolate . . . thereby obtaining May 1961 and November 1961, as the actual launch dates for the manned Redstone and manned orbital flights. It is hoped, however, that based on past experience, subsequent capsules can be more accurately scheduled through capsule systems checkout. Conversely, it must also be remembered that as yet none of the production capsules have been qualified during the maximum Q abort and reentry missions."

[47] Low, "Project Mercury Progress," an address before UPI Editors Conference, Washington, Sept. 9, 1960, NASA News Release 60–275; Low, comments, Oct. 5, 1965.

[48] For the significance of the AACB, see Robert L. Rosholt, *An Administrative History of NASA, 1958 to 1963,* NASA SP–4101 (Washington, 1966), 172–173; see also NASA News Release 60–260, Sept. 13, 1960.

[49] Richard M. Mansfield, "Project Mercury: Race or Pure Science?" *Virginian-Pilot and Portsmouth Star,* Sept. 11, 1960.

[50] "An Open Letter to Richard Nixon and John Kennedy," *Missiles and Rockets,* VII (Oct. 3, 1960), 10–11; John F. Kennedy, "If the Soviets Control Space They Can Control Earth," *Missiles and Rockets,* VII (Oct. 10, 1960), 12–13; "Nixon 'Declines' to Join Defense/Space Debate," *Missiles and Rockets,* VII (Oct. 24, 1960), 13; Richard M. Nixon, "Military has Mission to 'Defend' Space," *Missiles and Rockets,* VII (Oct. 31, 1960), 10–11. Cf. a similar set of questions and answers in *Western Aviation, Missile and Space Industries* (Nov. 1960). See also Edward C. Welsh, interview, Washington, Sept. 1, 1965.

[51] See Robert Hotz, editorial, "The Gathering Storm Over Space," *Aviation Week,* LXXIII (Nov. 7, 1960), 21; and "Sharp Defense/Space Changes Expected," *Aviation Week,* LXXIII (Nov. 14, 1960), 30.

[52] Hans W. Gatzke, *The Present in Perspective: A Look at the World Since 1945* (2 ed., Chicago, 1961), 188. See also Philip C. Jessup and Howard J. Taubenfeld, *Controls for Outer Space and the Antarctic Analogy* (New York, 1959), 200, 282.

[53] House Committee on Science and Astronautics, 86 Cong., 2 sess. (1960), *The Practical Values of Space Exploration,* Report No. 2091, July 5, 1960, 1. Cf. revision as House Report No. 1276, Oct. 2, 1961, 20–22.

[54] *Ibid.,* 54. Aside from the better illustrations and the updated figures on space costs and accomplishments, the August 1961 revision of this report contained one significant addition, namely a two-page (20–22) discussion in the national security section entitled "Interpreting The Race," which said in part:

"The fact that we are racing the Russians to the moon and the planets should not be allowed to obscure certain facets of the precise situation we are in.

"To begin with, it is essential to realize that sending men beyond earth's environment requires rockets of very high thrust—big boosters. The Soviets, who have about a 5-year jump on the United States in this field, have such rockets in operation. Our biggest ones are still in the development stage, although they are showing considerable promise. So we begin this particular phase of 'the race' under a marked handicap and doubtless will be in second place for some time to come.

"It is equally important, however, to recognize that 'getting there first' is only one part of the race. Two other parts are just as crucial:

1. What will we learn from our effort to explore beyond the Earth?

2. How will we use this knowledge after it is acquired?

"The Vikings had the technique to get to

the New World 'first,' but England, France, and Spain won the prizes. . . . With no intent to deprecate the notable achievements of the Soviet Union in space research, it can nonetheless be said that the broad scope of the American effort has—thus far at least—been outstanding in its scientific results. And, as subsequent parts of this report suggest, our free enterprise system has been quick to take advantage of the technological fall out.

"In summary, our international prestige and stature, so far as they are influenced by our space activities, depend on all three elements of 'the race'—not on one or two."

[55] Memo, Benjamine J. Garland to Project Director, "Possible Meteoroid Damage to Mercury," with enclosure, June 2, 1960, 3.

[56] Letter, Smith J. DeFrance to Alan B. Kehlet, "Information Requested by STG on Pressure Transducers and an Auxiliary Drag Device for Mercury," with enclosures, Sept. 16, 1960; memo, Caldwell C. Johnson to Faget, "Auxiliary Drag Device—Mercury," Nov. 2, 1960; John P. Mayer, comments, Sept. 8, 1965. Back in 1957 Avco had proposed a metallic drag chute shuttlecock configuration for the same purpose for the Air Force Man-in-Space studies. See also "Summary of Several Short Studies Pertaining to the Retro-Rocket System Capabilities for the Mercury Mission," NASA Project Mercury working paper No. 160, Nov. 9, 1960.

[57] The reinstatement of development work on the pneumatic impact bag followed after Gerard J. Pesman learned the details of more experiments on human impact at Wright-Patterson late in 1960. For a resume of this work see J. W. Brinkley, R. A. Headley, and K. K. Kaiser, "Abrupt Acceleration of Human Subjects in the Semi-Supine Position," paper, Symposium on Bio-Mechanics of Body Restraint and Head Protection, Naval Air Materiels Center, Philadelphia, Pa., June 14–15, 1961.

[58] Memo, Peter J. Armitage and E. N. Harrin to Chief, Operations Div., "Mercury Capsule Water Stability," Oct. 31, 1960.

[59] Memo, Harrin to Chief, Operations Div., "Static Water Stability Tests of Personal Egress Capsule," Jan. 10, 1961.

[60] "Project Mercury Status Report No. 8 for Period Ending October 31, 1960," STG, 17–18; "Astronaut Preparation and Activities Manual for Mercury-Redstone No. 3," NASA Project Mercury working paper No. 174, Feb. 6, 1961.

[61] Memo, Yardley and G. M. Preston to Silverstein, et al., "Summary of Conclusions Reached Regarding the CST Plans and Cape Checkout Plans for Capsules 5 (MR–2) and 7 (MR–3)," Sept. 9, 1960, 3. For MAC's home factory response to the field workers' difficulties with electrical, piping, sequencing, inspection, and cleanliness problems, see draft memo by H. Earle Moore and Walter F. Burke, "Quality Assurance—Project Mercury," Sept. 12, 1960.

[62] Memo, Richard Sachen and James T. Rose to W. H. Gray, "General Summary of Capsule Systems Tests on Capsule No. 7," Dec. 1, 1960, with enclosures. Convair/Astronautics had encountered the skin-cracking problem in 1955 during the Atlas development program. At that time no solution had been discovered.

[63] Memo, Jerome B. Hammack and Rose to W. H. Gray, "General Summary of Capsule Systems Tests on Capsule No. 7," Dec. 1, 1960, 5, 6. This memo, with enclosures 1–17, gives a detailed engineering history of the problems encountered during the systems testing of the first manned Mercury capsule. Although STG inspectors found 189 electrical and mechanical discrepancies in their final acceptance test, MAC's own inspectors had listed some 370 such discrepancies before their final clean-up prior to delivery.

[64] See Leutjen, "Ground Checkout and Launch Procedures," 3. Revised procedures for expediting checkout "squawk sheets" and discrepancy reports were issued shortly thereafter: see memo, Yardley and Preston to Hangar S Supervisors, "Cape Inspection Policy Clarification," Oct. 20, 1960.

[65] Letter, Williams to Commanding Officer, Air Force Missile Test Center, attention Lt. Col. R. D. Stephens, Sept. 6, 1960; "T–605 Operation, MR Mission," STG, Sept. 8, 1960; "MR–1 Mission Rules," STG, Nov. 2, 1960; letter, Williams to Kurt H. Debus, "Flight Safety Review for MR Missions," Sept. 22, 1960, with enclosure, "Flight Safety Review Plan"; letter, Williams to Cdr. DesFlotFour, "NASA Personnel Assignment for MR–1 Test," Sept. 28, 1960, with enclosures; memos, Low to Administrator, "Tests of Mercury Redstone 1 and Little Joe 5," Nov. 2, 1960; and "LJ–5 and MR–1 launchings," Nov. 4, 1960; Williams, Management Memorandum, No. 13, "Working Hours, Launch Operations Branch," Oct. 5, 1960.

[66] Letter, James P. Gleason to Kenneth E. BeLieu, Nov. 7, 1960. For one source of this concern, see Drew Pearson, "Space Shot

Moved to Election Eve," *Washington Post,* Nov. 2, 1960.

[67] Project Mercury Status Report No. 8"; "Project Mercury Discussion," briefing charts, Oct. 31, 1960.

[68] "Project Mercury Flight Test Report for Little Joe Mission No. 5 (capsule No. 3)," NASA Project Mercury working paper No. 166, Dec. 23, 1960; letter, Williams to R/A F. V. H. Hilles, Dec. 14, 1960; memo, Low for Administrator, "Report on Little Joe No. 5 and Mercury Redstone No. 1," Nov. 10, 1960. See also Fisher, comments, Sept. 15, 1965.

[69] Memo, North to Dir., Space Flight Programs, "Project Mercury PMP Charts," Sept. 21, 1960, explains why the chimp was eliminated from LJ-5. John C. Palmer, "Test Directive for Little Joe V," approved countdown procedures, undated. See also minutes, "Little Joe V AeroMedical Operations Review Meeting," Richard S. Johnston, secretary, July 12, 1960; "Mission Document for Little Joe No. 5 (Capsule No. 3)," NASA Project Mercury working paper No. 121, May 25, 1960.

[70] Low memo, Nov. 10, 1960; memo, Low to Asst. Administrator for Congressional Relations, "Mercury Redstone and Little Joe 5 Launchings," Nov. 16, 1960. The additional Little Joe airframe was suggested by Silverstein. Memos, William M. Bland, Jr., to Faget, "Visit of representatives of NAA-MD to STG," Feb. 1, 1960, and "Further Development of Little Joe Booster," Feb. 8, 1960; North to Silverstein, "Request for Approval Project Mercury Funding," June 27, 1960; Silverstein to Budget Office, "Budget on Approval of Project Mercury Funding," June 29, 1960. Cf. memo, C. J. Donlan to LRC Procurement Officer, "Contract NAS 9-59, Refurbished Little Joe Static Booster, Expedited Delivery," Nov. 16, 1960.

[71] Memo, Johnson to Faget, "Mercury Weight Growth—Effect upon Orbit Insertion Probability, Retrograde Maneuver, Parachute Loads, and Flotation," Nov. 22, 1960, 1-3. Johnson speculated on possibilities:

"The really interesting scheme requires starting all over. Consider six (6) Pioneer or Explorer second stage motors clustered together as a posigrade-retrograde power pack. . . .

"On the subject of parachutes and weights: it is quite likely that the impact skirt system and its associated 100 pounds of weight could be eliminated if the capsule impact attitude could be restricted to 'pilot feet first' and without much swing. The main difficulty now is the pilot's low tolerance to lateral acceleration. . . . This is not a proposal but it's worth thinking of."

See also Huss comments.

[72] Letter, Gleason to BeLieu, Nov. 3, 1960. For the description of events following, see memos, Low to Administrator, "MR-1 Launching," Nov. 7, 1960; Low to Dir., Space Flight Programs, "Mercury-Redstone 1 Launching," Nov. 14, 1960; Low to Administrator, "MR-1 Launching," Nov. 18, 1960.

[73] For news criticism in the wake of MR-1, see William Hines, "Mercury Failure Puts Early Flight in Doubt," Washington *Evening Star,* Nov. 21, 1960; "Astronaut Flight Still Slated in '61," *New York Times,* Nov. 26, 1960; Louis Kraar, "Man in Space Tests Far Behind Schedule," *Wall Street Journal,* Nov. 28, 1960; and "Space Experts Sniping at Mercury," *Space Age News,* Nov. 21, 1960.

[74] Memo, Low to Administrator, "Attempted Launching of MR-1," Nov. 21, 1960; Hammack, interview, Houston, Feb. 13, 1964; and memo report, Hammack for Proj. Dir., "Attempted Launch of Mercury-Redstone No. 1 Mission on November 21, 1960," Nov. 23, 1960.

[75] Memo, Low to Administrator, "Explanation of MR-1 Failure," Nov. 23, 1960; Joachim P. Kuettner, interview, Huntsville, April 28, 1964.

[76] Memo, Low to Dir., Space Flight Programs, "PMP Briefing on December 2, 1960, Project Mercury," Nov. 28, 1960; and Low comments.

[77] Memo, Low to Administrator, "MR-1 Launch Information," Dec. 15, 1960. For retest preparations, see "Mercury-Redstone, NASA, LOD-LOB, Master Operational Schedule," rev. Nov. 15, 1960, for MR-1, Report No. M-LOD-G-TR-49.4-60; rev. Dec. 2, 1960, for MR-1A, Marshall Space Flight Center. Ms., "MR-1A Review," STG, Dec. 17, 1960.

[78] Memo, Low to Administrator, "Mercury-Redstone 1 Launching," Dec. 20, 1960. See also Jerome B. Hammack and Jack C. Heberlig, "The Mercury Redstone Program," paper, American Rocket Society, Space Flight Report to the Nation, New York City, Oct. 9-15, 1961, 16-17.

[79] Memos, Howard C. Kyle to Mercury Flight Dir., "MR-1 Launch on December 19, 1960—observations"; Teewyn Roberts to Flight Dir., "Report on Test No. 5111," Dec. 20, 1960; and Stanley C. White to Flight Dir.,

"MR–1A Test No. 5111," Dec. 20, 1960. For the later post-flight inspection of MR–1A, see letter, Purser to Burke, "Contract NAS 5–59; Post-Flight Evaluation of Capsule Number Two," Jan. 31, 1961, with two enclosures. See also Chap. X, footnote 26.

[49] Memo, North to Dir., Space Flight Programs, "Mercury Capsule Changes and Flight Schedule," Dec. 6, 1960:

"Open loop operation of the Abort Sensing and Implementation System (ASIS) is a change which does not detract from the effectivity of the system. This change, in fact, makes the system more reliable and effective because a pilot who is placed in the control loop has the ability to assess whether a true abort situation exists. In this concept, the pilot would get a red light indication that an abort is called for but would manually activate the escape sequence. The inherent aerodynamic stability and high structural strength of the Redstone should provide a sufficient time constant between capsule abort light indication and time for abort decision. The pilot, after observing the abort light, can either immediately abort, if he is in a critical flight regime, or he can rely on secondary cues such as changes in acceleration, changes in attitude, and radio voice transmissions from visual observers or telemeter monitors. Although it is reasonably clear that the Redstone should be flown with an open loop ASIS, the Atlas operational procedure is not yet resolved because allowable pilot reaction time will be somewhat less. I feel, however, that experience with the manned Redstone will convince us that the manned Atlas should also be flown open loop. Incidentally, three Atlas ASIS systems have been flown open loop to date; two would have caused inadvertent aborts."

Warren North was himself a test-pilot engineer, and this viewpoint became even stronger over the next year; see North and Walter Williams, "The NASA Astronaut Program," *Aerospace Engineering*, XX (Jan. 1962), 13–15.

[51] For an overview of the meetings and conferences on the MA–1 failure, see James M. Grimwood, *Project Mercury: A Chronology*, NASA SP–4001 (Washington, 1963), 111, 112. On the MA–1 review of Nov. 16, 1960, see "Mercury-Atlas Program," briefing brochure Nos. AD–60–0000–02356 and AT–60–0829–00415, undated. Minutes, "Summary of Test Programs and Recommendations for MA–2 Launch," Sjoberg, secretary, Nov. 16, 1960; Ms. notes, Purser, "STG Position on MA–1," Dec. 20, 1960; draft letters, Purser to Donlan, Faget, and James A. Chamberlin, Dec. 31, 1960, and Jan. 1, 1961; memo, Low to Dir. Space Flight Programs, "Project Mercury Status," Dec. 29, 1960; and Richard V. Rhode, interview, Washington, Jan. 18, 1966.

[52] *A Chronology of Missile and Astronautics Events*, 135; Sheldon, "The Challenge of International Competition," 11, 26, and comments, Aug. 12, 1965.

[53] G. Pokrovsky, "We Give Space to the Russians," *Washington Daily News*, Dec. 5, 1960; "Lead-Footed Mercury," *Time*, Dec. 5, 1960; "Man in Space," editorial, *New York Times*, Dec. 2, 1960.

## *Chapter X*

[1] *NASA Fifth Semiannual Report to Congress, October 1, 1960, through June 30, 1961*, 153. This report, not published until July 11, 1962, is highly anachronistic (see pp. 5, 6) and should be used with caution. See also memo, Aaron Rosenthal to Dir., Office of Space Flight Programs, "Temporary Reassignment of Manpower Spaces," with enclosures on STG complement requirement for fiscal 1962, Dec. 5, 1960.

[2] Eugene M. Emme, *Aeronautics and Astronautics: An American Chronology of Science and Technology in the Exploration of Space, 1915–1960* (Washington, 1961), 134, 139–151; *STL Space Log* (Jan. 1961), 24, 3–8. Charles S. Sheldon II has corrected the poundage figures in terms of lifting capacity to 100 nautical mile altitude. Official comparisons sometimes unfairly counted the weights of U.S. rocket casings and not those of U.S.S.R. casings.

[3] Senate Committee on Aeronautical and Space Sciences, 88 Cong., 1 sess. (1963), *Documents on International Aspects of the Exploration and Use of Outer Space, 1954–1962*, May 9, 1963, 186.

[4] The informant was Lt. Col. Paul D. Hickman, of the Armed Forces Industrial College. See House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *A Chronology of Missile and Astronautics Events*, 139–140; House Committee on Science and Astronautics, 87 Cong., 2 sess. (1962), *Aeronautical and Astronautical Events of 1961*, 1–2; and "U.S. Officer Says 2 Reds Died in Space," Newport News *Daily Press*, Jan. 15, 1961. Soviet spokesmen later denied this report, of course, and most informed American opinion credits the Soviet denial. Two

U.S.S.R. attempted launchings of Mars probes on October 10 and 14, 1960, may have confused this issue. For an important demurrer, see the letter by Julius Epstein, a research associate of the Hoover Institute of Stanford University, reprinted in the *Congressional Record* on Aug. 6, 1965: "Open Versus Secret Procedures in Space Programs," pp. 18813–18814.

[5] *Documents on International Aspects of . . . Outer Space,* 188. For some perspective on the larger interregnum and the search for a national space program between 1958 and 1962, see House Committee on Government Operations, 89 Cong., 1 sess. (1965), *Government Operations in Space* (Analysis of Civil-Military Roles and Relationships), 49–71.

[6] Ms., "Report to the President-Elect of the Ad Hoc Committee on Space," Jerome B. Wiesner, chairman (unclassified version), Jan. 12, 1961, 11, 12.

[7] Ms., "Report to the President-Elect of the Ad Hoc Committee on Space," Wiesner, chairman (classified version), Jan. 10, 1961, 17. The other members of this committee were Kenneth BeLieu, Trevor Gardner, Donald F. Hornig, Edwin H. Land, Max Lehrer, Edward M. Purcell, Bruno B. Rossi, and Harry J. Watters.

[8] At a press conference on Oct. 26, 1960, Robert R. Gilruth was asked about the possibility of using the Titan rather than the Atlas for orbital flight. Gilruth said he preferred the Atlas, pointing out that the technical problems connected with it were being solved, whereas those associated with the Titan were nowhere near solution. The fact that the second stage of the two-stage Titan ignited in flight presented additional problems to orbital flight, he said. In contrast all three Atlas engines ignited at liftoff. Gilruth actually drafted a letter intended for Maj. Gen. Osmond J. Ritland, commander of the Air Force Ballistic Missile Division, asking for a briefing on the possible application of the Titan to the Mercury program. The letter (Gilruth to Ritland, Jan. 18, 1961) was never mailed, primarily because the conceptual development of the follow-on program after Mercury was beginning to take shape. In May 1961 Robert C. Seamans was sold on the Titan II as a launch vehicle for Mercury Mark II, and thereafter NASA and DOD agreed to support each other's use of Titan II and III respectively; Seamans, interview, Washington, Sept. 1, 1965.

[9] House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *Third Annual Report in the Fields of Aeronautics and Space,* Jan. 18, 1961, XVI, 8–9; Paul E. Purser, interview, Houston, March 15, 1965; George M. Low, interview, Houston, March 19, 1964.

[10] *Washington Post,* Jan. 12, 1961; "Washington Roundup," *Aviation Week,* LXXIV (Feb. 6, 1961), 5; Washington *Evening Star,* Jan. 12, 1961; Newport News *Daily Press,* Jan. 27, 1961. The Wiesner Report admitted that the committee's review of the nation's space program had been made hastily.

[11] *Public Papers of the Presidents of the United States: Dwight D. Eisenhower, 1960–61* (Washington, 1961), Item 421, 1038, "Farewell Radio and Television Address to the American People," Jan. 17, 1961. Eisenhower had warned: "In the councils of government, we must guard against the acquisition of unwarranted influence, whether sought or unsought, by the military-industrial complex. The potential for the disastrous rise of misplaced power exists and will persist. . . . We must never let the weight of this combination endanger our liberties or democratic processes. . . ."

[12] On the "military-industrial complex" problem, see George T. Hayes, ed., *The Industry-Government Aerospace Relationship,* 2 vols. (Menlo Park, Calif., May 1963), Stanford Research Institute Project No. IS–4216; Robert Hotz, "Gathering Storm Over Space," *Aviation Week,* LXXIII (Nov. 7, 1960), 21; Hotz, "Sharp Defense/Space Changes Expected," *Aviation Week,* LXXIII (Nov. 14, 1960), 30–31. See other articles in *Aviation Week,* LXXIV (Jan. 16, 1961), 21; (Jan. 30, 1961), 21, 34; Robert L. Rosholt, *An Administrative History of NASA, 1958–1963,* NASA SP–4101 (Washington, 1966), 184; House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *Military Astronautics (Preliminary Report),* Staff report No. 360, May 4, 1961.

[13] For some of the scientists' criticism of Mercury, see Jay Holmes, *America on the Moon: The Enterprise of the Sixties* (New York, 1961), 72–82. The most prevalent scientific objection to Mercury was expressed by the question "Why put the sensitive stomach and heart of a man out in space when his other senses can be sent out there with man staying on the ground but in the loop?" Douglas R. Lord, interview, Washington, Sept. 3, 1965.

[14] House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *NASA Authorization, Hearings,* Part I, March 13–April 17, 1961, 4, 192, 195, 199, 213. Cf. Rosholt, *Administrative History of NASA,* 136–137, 184, 190–195 for more details on the extremely complex financial history of NASA during this period. See also Merton J. Peck and Frederic M. Scherer, *The Weapons Acquisition Process: An Economic Analysis* (Boston, 1962), 100. It is perhaps significant that what purports to be a House Committee on Science and Astronautics manuscript, entitled "Project Mercury: A Preliminary Progress Report," dated October 1960, accurately estimated (at last) a completion cost for Project Mercury at $393 million, of which approximately $110 million would be spent on the McDonnell contract for the spacecraft.

[15] "Interim Report," Joint Air Force/NASA Ad Hoc Committee on Atlas Boosted Space Systems, Jan. 19, 1961. Richard V. Rhode, interview, Washington, Dec. 30, 1964; Bernhard A. Hohmann, interview, Houston, Sept. 16, 1965. Richard V. Rhode pursued the method with which the Atlas contractor would fit the "belly band" to the booster's top sections, since there were small metal appendages that would have to be ground flush to the booster's surface. He was particularly interested in how they would prevent the metal from being undercut and thereby weakening the structural strength even more. General Dynamics responded that they had a technician with capability to prevent undercutting. Rhode asked to be shown. After seeing the proof, he directed that this individual be sent to the Cape to perform this part of the "fix." Rhode, interview, Washington, Jan. 18, 1965.

[16] Letter, Purser to Rhode, Jan. 10, 1961; Ms. notes, Purser, "STG–773, 67–D Instrumentation," Jan. 3, 1961; Ms., "Agenda—Abort Parameters," Jan. 4, 1961. Seamans and Abe Silverstein of NASA Headquarters; James R. Dempsey of Convair/Astronautics, and the Secretaries of the Air Force and the Department of Defense were all involved in telephonic conferences behind the scenes on the MA–2 decisions. For the final decision to go with the "horse collar," see Ms., Purser, "Notes for Rhode Committee: Status of MA–2," Feb. 13, 1961.

[17] Rhode, "The First Hundred Seconds," paper, American Rocket Society Conference on Launch Vehicle Structures and Materials, April 3, 1962. Rhode here applied his experience with the Electra and the Atlas to Saturn problems of fuel slosh, acoustics, panel flutter, buffeting, and wind effects during the first 100 seconds. "In a structural sense there is really no such thing as a 'launch vehicle,'" he said.

[18] Holmes, *America on the Moon,* 189–190; Hotz, "New Vigor for Space Program," *Aviation Week,* LXXIV (Jan 16, 1961), 21.

[19] James E. Webb, interview, Washington, Sept. 3, 1965; Webb, address before Science Convocation at Brandeis University, Waltham, Mass., Nov. 7, 1965, NASA News Release. See also "Washington Roundup," *Aviation Week,* LXXIV (Jan. 30, 1961), 21.

[20] Holmes, *America on the Moon,* 190–192; Senate Committee on Astronautical and Space Sciences, 88 Cong., 1 sess. (1963), *NASA Authorization for Fiscal Year 1964, Hearings,* Part 1, 5–6; NASA biography of James E. Webb, Jan. 27, 1964. For details of Webb's background, see Senate Committee on Aeronautical and Space Sciences, 87 Cong., 1 sess. (1961), *Nomination of James Edwin Webb to be Administrator of the National Aeronautics and Space Administration.*

[21] "Washington Roundup," *Aviation Week,* LXXIV (Jan. 30, 1961), 21; "Kennedy Appoints Webb to Direct NASA," *Aviation Week,* LXXIV (Feb. 6, 1961), 29; Hotz, "Success and Disappointment in Space," *Aviation Week,* LXXIV (Feb. 6, 1961), 21; Newport News *Daily Press,* Feb. 5, 1961; Holmes, *America on the Moon,* 192. Webb's appointment was confirmed by the Senate on Feb. 9, and he was sworn in on Feb. 15, 1961.

[22] Letter, Overton Brooks to John F. Kennedy, March 9, 1961; Kennedy to Brooks, March 23, 1961; see also "Washington Roundup," *Aviation Week,* LXXIV (Jan. 16, 1961), 25; "Cooperation Theme is Stressed by NASA and Defense Officials," *Aviation Week,* LXXIV (Jan. 30, 1961), 34; and "Washington Roundup," *Aviation Week,* LXXIV (Feb. 6, 1961), 25.

[23] Excerpts from messages compiled by Purser, special assistant to director, STG, re status of spacecraft No. 5. During one of the McDonnell tests, when the air leakage rate was being checked, the inspectors found that gas seepage was too great. The best seal they could obtain left a leakage rate of 1725 cc./min. at 4.9 p.s.i. for 45 minutes, as against the specified maximum rate of 650 cc. The defect causing this was found at the umbilical connector and traced to warpage of the capsule frame. McDonnell reworked the struts and stringers to make a better fit. This is but

one sample from daily reports to STG about the rework status of one selected component. Afterward, on July 5, 1960, STG approved a spacecraft leak rate of 1000 cc per minute. Memo, Richard S. Johnston, Asst. Head, Life Systems Branch, to Chief, Flight Systems Div., "Capsule Leakage Rates," July 5, 1960.

[24] Message, John J. Williams, Launch Operations, Marshall Space Flight Center, to G. Merritt Preston, STG Cape Operations, Oct. 4, 1960; "Postlaunch Report for Mercury-Redstone No. 2 (MR–2)," NASA/STG, Feb. 13, 1961; NASA News Release 61–14–1, "Project Mercury Background," Jan. 28, 1961. For the MR–2 mission directive, see NASA Project Mercury working paper No. 138, dated Apr. 15, 1960, rev. Nov. 29, 1960, and Jan. 27, 1961.

[25] David S. Akens, Paul K. Freiwirth, and Helen T. Wells, *History of the George C. Marshall Space Flight Center* (Huntsville, Ala., May 1961), Vol. I. Appendix B, "Mercury-Redstone Chronology," 28, 32; Francis E. Jarrett, Jr., and Robert A. Lindemann, "Historical Origins of NASA's Launch Operations Center to July 1, 1962," Kennedy Space Center Historical Monograph No. 1, Cocoa Beach, Fla., Oct. 1964, B–26.

[26] Akens, Freiwirth, and Wells, *History of Marshall Space Flight Center*, Vol. I, 32; memo, E. D. Geissler, Aeroballistics Div., Marshall Space Flight Center, to STG, "Project Mercury-Redstone: Trajectory Data for MR–2," Jan. 23, 1961; memo, Walter C. Williams, Operations Dir., STG, to Marshall Space Flight Center, "Launch Trajectories for MR–2 and Subsequent Flight," Dec. 20, 1960; "Technical Information Summary of Mercury-Redstone Mission MR–2," Marshall Space Flight Center, Jan. 20, 1961. Williams' 12-g nominal reentry decelerations were not connected with the 12-g emergency maximum advocated by the Air Force in 1958 for the "man-in-space" study program. The 12-g maximum desired for the MR–2 mission was set for two reasons: (1) It represented the midway point between a normal Mercury-Atlas reentry (about 8 g) and the worst Mercury-Atlas reentry (about 16 g); and (2) normal reentry for the Mercury-Redstone was about 11 to 12 g. STG felt it was necessary to study the g-load effects on the chimpanzee in this range. The fact that both acceleration and deceleration g loads surpassed 12 served to prove the supine couch concept.

[27] "Project Mercury Technical Information Summary of Mercury-Redstone Mission No. 2 (Capsule No. 5)," NASA/STG, Jan. 24, 1961; "Technical Information Summary Concerning Mercury-Redstone Mission MR 2," MSFC report TPR–M–60–1; NASA News Release 61–14–2, "MR–2 Flight Profile," Jan. 28, 1961; "Project Mercury Background."

[28] NASA News Release 61–14–3, "Animal Flight Program," Jan. 28, 1961; "Information Guide for Animal Launching," July 23, 1959; "Countdown and Procedures (Animal Subject) for Project Mercury Flight MR–2," USAF Aeromedical Field Laboratory, Holloman Air Force Base, N. Mex., Dec. 1960.

[29] Norman E. Stingely, John D. Mosely, and Charles D. Wheelwright, "MR–2 Operations," in *Results of the Project Mercury Ballistic and Orbital Chimpanzee Flights,* NASA SP–39 (Washington, 1963), 7.

[30] "Recovery Operations Requirements for Mercury-Redstone Test No. 2," STG, undated [about Jan. 12, 1961]; "Mercury Recovery Forces," NASA fact sheet, undated; Message, Cdr., DesFlotFour, to STG, "Public Information for MR–2," Jan. 5, 1961. The helicopters were from Marine Aircraft Group 26, the Mercury project officer of which was 1st Lt. Wayne E. Koons, USMCR.

[31] Letter, Walter Williams, STG, to Cdr., DesFlotFour, re NASA personnel assignment for MR–2 test, Jan. 6, 1961.

[32] "Master Operational Schedule, MR–2," Marshall Space Flight Center, Jan. 20, 1961, 5–26, 27–30, 32–47, 48–77; *Final Report: Mercury-Redstone Project Launch Operations,* Marshall Space Flight Center, May 28, 1962, 121, Appendix L, "MR–2 Daily Log Summary," 1–4.

[33] "MR–2 Flight Test Profile—Operations Directive No. 1904, Mercury - Redstone Launch," Air Force Missile Test Center, Jan. 5, 1961, 4–10.

[34] *Ibid.* Ham's depth of respiration was measured by a pneumograph consisting of a rubber tube filled with copper sulfate solution. Electrical resistance of the solution varied as the tube was stretched. At one point during the testing of sensors for measuring the primate's respiration, technicians discovered that when the pneumograph was attached high on the thorax, the chimp breathed low and vice versa. One solution was to use two pneumograph straps in conjunction. *Results of the Project Mercury Ballistic and Orbital Chimpanzee Flights;* A. D. Catterson, MSC Medical Support Operations, interview, Houston, Oct. 23, 1964.

[35] "Countdown and Procedures (Animal Subject) for MR–2"; "Animal Flight Pro-

gram"; *Marshall Star,* Feb. 1, 1961; Stingely, Mosely, and Wheelwright, "MR–2 Operations," 9–11. Each animal received 15 commercial food pellets and a fourth of an orange at a feeding. One 12-ounce serving was given at about T minus 20 hours and another at T minus 15 hours. Water intake was limited to 800 cc. from T minus one day through recovery. The name "Ham" also honored the commander of Holloman Aeromedical Laboratory, Lt. Col. Hamilton Blackshear.

[36] "MR–2 Flight Test Profile—Directive 1904." Staff members under the operations director had a variety of duties and responsibilities. For example, the launch director, located in the blockhouse, reported on the readiness of the launch vehicle; the launch conductor, also in the blockhouse, was responsible for detailed supervision of launch operations; the capsule test conductor had a similar duty on the countdown; and the flight director, located in the Mercury Control Center, had detailed flight-control responsibility from liftoff to touchdown.

[37] Memo, Tecwyn Roberts, Flight Dynamics Officer, to Flight Director, "Report on Test 3805," Feb. 2, 1961; penciled notes on the countdown of MR–2, anon., Jan. 31, 1961. The origin of the popular space term "A.OK" is a matter of widespread public interest. In reporting the *Freedom 7* flight, the press attributed the term to Astronaut Shepard, and indeed NASA News Release 1–61–99, May 5, 1961, has Shepard report "A.OK" shortly after impact. A replay of the flight voice communications tape disclosed that Shepard himself did not use the term. It was Col. John A. "Shorty" Powers who reported Shepard's condition as "A.OK" in a description of the flight. Tecwyn Roberts of STG and Capt. Henry E. Clements of the Air Force had used "A.OK" frequently in reports written more than four months before the Shepard flight. Roberts attributed coinage of the term to Paul Lein, of the Western Electric Co., while the tracking network was being constructed. Lein, however, said that "A.OK" was a communal development among communications engineers while circuits were first being established downrange from Cape Canaveral. The voice circuits at first gave poor quality. The bands were narrow, and the systems operated on 1500 cycles. There was much static and background noise. Words got lost in voice circuit systems checks. To make transmissions clearer, the communicators started using "A.OK" because the letter "A" has a brilliant sound. Other sources claim that oldtime railroad telegraphers used "A–OK" as one of several terms to report the status of their equipment. Be that as it may, Powers, "the voice of Mercury Control," by his public use of "A.OK," made those three letters a universal symbol meaning "in perfect working order."

[38] Penciled notes on MR–2 countdown; memo, William S. Augerson, Life Systems Group, to Christopher C. Kraft, Mercury Control Center Flight Dir., "Blockhouse Medical Monitoring of MR–2," Feb. 6, 1961; W. J. Kapryan, "Postlaunch Report for MR–2," Feb. 2, 1961. Some flight notes on MR–2, author unknown, dated Feb. 1961, indicated that the inverter had operated at temperatures as high as 200 degrees F.

[39] "Postlaunch Report for MR–2," 9; NASA News Release, Cape Canaveral, Jan. 30, 1961; Roberts memo; memo, Warren J. North, Head, Manned Satellites, NASA Hq., to Franklyn W. Phillips, NASA Hq., "MR–2 Flight Results," Feb. 1, 1961; tape of press conference following MR–2 launch, Cape Canaveral, Jan. 31, 1961. Cf. Carl R. Huss comments, Oct. 5, 1965.

[40] "Postlaunch Report for MR–2," 9; memo, North to STG, "Retrocontrollers Comments," Feb. 9, 1961. Brief accounts of Ham's flight may be found in Kenneth F. Weaver, "Countdown for Space," *National Geographic,* CXIX (May 1961), 725–734; and in Judith Viorst, *Projects: Space* (New York, 1962), 37–38.

[41] Memo, Morton Schler, capsule environment monitor, to Kraft, "MR–2 ECS Flight and Postflight Summary," Feb. 6, 1961.

[42] "Mercury-Redstone II Flight Parameters," chart, Feb. 7, 1961; "Calculated Preflight Trajectory Data for MR–2," Project Mercury working paper No. 168, Jan. 19, 1961. See also North memo.

[43] *NASA Fifth Semiannual Report to Congress.* See also NASA films, *MR–2 Launch,* March 1961, and *Sixth Quarterly Report,* April 1961.

[44] "Postlaunch Report for MR–2," 10; MR–2 flight parameter chart; tape of press conference following MR–2 flight; some flight notes on MR–2, anon., dated Feb. 1961; House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *Project Mercury, Second Interim Report,* 34–37; Wayne E. Koons and James L. Lewis, interviews, Houston, Sept. 16, 1965. Robert F. Wallace, an STG information officer on the scene, reported that Ham was excited when returned to Hangar S after

his flight. Being unable to debrief his handlers, Ham alone knew at this time how grueling his flight had been. Flashbulbs and crowding newsmen made him highly agitated, and he snapped at several people. Back in his trailer, his suit was not removed until he became calm, and at that time a famous "grin" photograph was made. Later, when his handler led him back toward a capsule for pictures requested by the TV crews, Ham again became highly perturbed. It took three men to calm the "astrochimp" for the next round of pictures. On April 2, 1963, Ham was given to the National Zoological Park, Smithsonian Institution, Washington, D.C., where for the past several years he has been in good health and has thrilled many children.

[45] The amount of water in the spacecraft caused great concern to members of STG's Life Systems Group when they found the heatshield had punctured holes in the lower pressure bulkhead. Life Systems renewed studying alternatives, making either optional or impossible the deployment of the landing bag. More drop tests were undertaken by the Aeromedical Biophysics Group of the Wright Air Development Division. Simulating the Mercury drop rate of about 30 feet per second, the Wright group found that human test subjects could sustain impacts of about 35 g and recover from "a confused state" in about five seconds. STG considered this within fairly safe limits for an interim measure, but the margin of safety was too small to accept for the routine operation of a Mercury mission. Memo, Gerard J. Pesman to Assoc. Dir., "Use of Impact Bag for Water Landings," Feb. 13, 1961. In all of the manned missions the impact bag was deployed.

[46] See R. I. Johnson, et al., "The Mercury-Redstone Project," Saturn/Apollo Systems Office, Marshall Space Flight Center, June 1964, 8–9. Cf. Huss comments. Regarding the impact bag problems at this time, see memo, Rodney G. Rose to Chief, STG Engineering Div., "Summary of Air Drop and Fatigue Program with Production Capsule No. 5," May 4, 1961, and Ms. paper, "Project Mercury Water Landing Problems," presented to 30th annual AIAA meeting, New York City, Jan. 24, 1962.

[47] Purser, "Notes on Capsule Review Board Meeting," Jan. 20, 1961. The conception of Mercury Mark II (or what was named Project Gemini almost a year later) was taking place at this time. See memo, Purser to STG Dir., "Atlas Modifications, Cost, and Scheduling," Jan. 17, 1961. Message, Hohmann and Robert H. Brundin to Philip E. Culbertson, re tests of the restraining band to reduce the discontinuity stresses in the M/A station 502 area, Jan. 16, 1961.

[48] Seamans interview; "MA–2 Mission Directive," NASA Project Mercury working paper No. 140, June 24, 1960, rev. Aug. 11, 1960, Jan. 29, 1961, and Feb. 9, 1961; Donald T. Gregory, "Technical Information Summary of Mercury-Atlas Mission No. 2 (Capsule No. 6)," Feb. 10, 1961.

[49] Rhode interview. Owing to airline engineers' strike, Rhode flew to the Cape via a routine Air Force logistics flight, arriving just in time to climb the gantry and personally inspect the "fix."

[50] Webb interview; memo, George M. Low to Administrator, "Mercury-Atlas 2 Launch," Feb. 18, 1961; "Calculated Trajectory Data for MA–2," NASA Project Mercury working paper No. 163, Dec. 7, 1960.

[51] "Proceedings of the Mercury-Atlas Booster Reliability Workshop," San Diego, July 12, 1963, passim.

[52] Low, interview, Houston, Sept. 15, 1965; Ritland, interview, Andrews AFB, Dec. 30, 1964; Gilruth, interview, Houston, Mar. 18, 1964; P. E. Culbertson, comments, Aug. 16, 1965; Paul P. Haney, comments, Sept. 15, 1965; Purser, notes on MA–2 launch as relayed from Mercury Control Center, Feb. 21, 1961.

[53] "Post Launch Report for Mercury-Atlas No. 2 (MA–2)," STG, March 13, 1961, 161. An unidentified ship, a tanker flying a hammer-and-sickle flag, but apparently without any unusual radar antennas, also was able to see the unusual reentry. Memo, Donald C. Cheatham to Assoc. Dir., "Russian Ship in MA–2 Primary Landing Area," March 8, 1961.

[54] Memo, North to Administrator, "Preliminary MA–2 Flight Results," Feb. 23, 1961. Many NASA engineers and managers think of MA–2 as being "the day Mercury won its spurs" from the Air Force because in retrospect it represented the only potentially serious difference of opinion with the military services throughout the program; see Low comments.

[55] "Press Conference; Mercury-Atlas No. 2," Cape Canaveral, Feb. 21, 1961. See also John H. Glenn, Jr., "We're Going Places No One Has Ever Traveled in a Craft No One's Flown," *Life*, L (Jan. 27, 1961); Loudon Wainwright, "Chosen Three for First Space Ride," *Life*, L (March 3, 1961). For the Atlas manufacturer's postflight analysis, see

## FOOTNOTES

A. F. Leondis, "Project Mercury Structural Dynamic Analysis (Atlas 67D; MA-2)," Convair/Astronautics report No. AE 61-0743, Aug. 10, 1961.

[56] "The Mercury-Redstone Project," 5-37.

[57] *Ibid.*, 8-15. Before a press conference on February 8, 1961, President Kennedy had cautioned against a premature effort to "put a man in space in order to gain some prestige and have the man take a disproportionate risk." On February 28, Webb announced the President's order for a thorough review of the nation's space programs, and on March 2 a group from the President's Science Advisory Committee was already on tour and at the Atlantic Missile Range for a briefing on Project Mercury. See *Aeronautical and Astronautical Events of 1961*, 5, 8, 9.

[58] Joachim P. Kuettner, note for Dr. von Braun, Feb. 7, 1961; memo, Kuettner to von Braun and others, Marshall Space Flight Center, "Recommendation to Space Task Group on Manned Mercury-Redstone Flight," Feb. 7, 1961; "Daily Journal," Launch Operations Directorate—Marshall Space Flight Center, Feb. 6, 1961.

[59] Memo, Emil P. Bertram to Kurt H. Debus, "MSFC Meeting on MR-3 Manned Flight," Feb. 10, 1961; message, Debus to Kuettner, undated [about Feb. 12, 1961] re Launch Operations Directorate reply to Kuettner's memo of Feb. 7, 1961. See table 8-3 in Johnson et al., "The Mercury-Redstone Project," 8-15. The first priority list of weak "components" included the thrust controller, vibrations, cutoff arming timer, abort sensors, peroxide tank pressure regulator, peroxide system cleanliness, and a liquid oxygen manhole leak.

[60] Memos, North to Dir., Space Flight Programs, "Mercury Status as of March 2, 1961," Mar. 3, 1961, 2, 3; Wernher von Braun to Marshall Space Flight Center, "Sensitivity of Mercury Launching Dates," March 3, 1961.

[61] Message, Marshall Space Flight Center to STG, March 15, 1961; "Project Mercury Status Report No. 10 for Period Ending April 30, 1961," NASA/STG, 31; memo, Jerome B. Hammack, STG Cape Operations, to Project Dir., "Mercury-Redstone Booster Development Flight (MR-BD)," March 26, 1961.

[62] Letters, Brooks to Kennedy, March 9, 1961; Kennedy to Brooks, March 23, 1961. See also Air Force replies to these and other charges in House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *Defense Space Interests, Hearings*, March 17-23, 1961. Purser in his log for Gilruth, March 7, 1961, reported ushering the Hornig panel around Mercury sites from March 1 through 4: "All the comments I overheard were favorable. I also received very favorable direct comments from Dr. Hornig and the various panel members."

[63] Lloyd V. Berkner and Hugh Odishaw, eds., *Science in Space* (New York, 1961). See Holmes, *America on the Moon*, 193-195. See also the special issue devoted to "Space Exploration in the Service of Science" of *Bulletin of the Atomic Scientists*, XVII (May-June 1961), 169-240.

[64] House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *Hearings, 1962 NASA Authorization*, Part I, testimony of Abe Silverstein, March 14, 1961, 77, 94, 99.

[65] Luncheon talk by James E. Webb, NASA Administrator, to the American Astronautical Symposium, Washington, D.C., March 17, 1961.

[66] The steps leading to the decision for an accelerated U.S. space program to include landing an American on the moon before 1970, as presented to the Congress on May 25, 1961, are to be detailed in subsequent NASA histories.

[67] Senate Subcommittee of the Committee on Appropriations, 87 Cong., 1 sess. (1961), *Independent Offices Appropriations, 1962, Hearings*, testimony of Hugh L. Dryden, 642-643, 656.

[68] See "The Expanded Space Program," *Historical Sketch of NASA* (EP-29), 27-35.

[69] "Technical Information Summary of Little Joe 5-A (Capsule No. 14)," STG, March 6, 1961, 1-3; "Recovery Operations Requirement for Little Joe Test No. 5-A," undated; and Low comments. See pp. 291-293.

[70] Table adapted from memo, Low to Administrator, "Little Joe 5A Test," March 16, 1961. See also "Mission Directive for Little Joe No. 5A," NASA Project Mercury working paper No. 177, March 7, 1961, 3-1.

[71] Memo, North to Administrator, "Preliminary Flight Results, Little Joe 5-A," March 20, 1961. See also memo, Low to Dir., Space Flight Programs, "Little Joe 5-B Preparation Schedule," March 24, 1961. The fact that both primary and secondary main parachutes deployed immediately after the escape tower jettisoned complicated "quick-look" observations: see transcript, "Press Conference, Little Joe VI [LJ-5A], March 18, 1961," with Robert

L. Krieger and William M. Bland, Jr., at Wallops Island.

[72] Norman F. Smith and Chauvin, "Post-launch Report for Mercury Little Joe No. 5A (LJ–5A)," STG, April 11, 1961, 1. Lewis Fisher, in comments, Sept. 15, 1965, has said that "Little Joe 5A was anything but unedifying. . . . This type of failure may have easily occurred on a Mercury-Atlas flight with very severe program impact had not the Little Joe 5 series pinpointed and fixed a marginal design condition."

[73] Memo, unsigned, "Publicity Releases on Mercury," Marshall Space Flight Center, Feb. 8, 1961.

[74] "Information Plan: Redstone Development Test: MR–BD," NASA, March 21, 1961, 2. For an example of this policy, see NASA News Release 61–57, "Mercury Redstone Booster Development Test," March 22, 1961. One of the most famous of publicity fact sheets, issued by STG from Langley Field on April 10, 1961, was entitled simply "'*IF*': A Study of Contingency Planning for the Project Mercury Mission."

[75] "The Mercury-Redstone Project," 8–16; "Final Report: Mercury Redstone Project Launch Operations," Appendix O, 2; memo, Geissler, "Project Mercury-Redstone: Trajectory Data for MR–BD," March 20, 1961; "Master Operational Schedule for MR–BD," Marshall Space Flight Center, March 6, 1961; memo, S. Snyder to NASA Technical Personnel, "Mercury-Redstone (MR–BD) Launch," March 23, 1961.

[76] Hammack memo. Mercury working paper 178 was by J. W. Maynard, T. J. Skopinski, and P. S. Leatherman, "Calculated Preflight Trajectory Data for Redstone Booster Test (MR–BD)," March 17, 1961.

[77] Memo, Low to Administrator, "Mercury Redstone Booster Development Test," March 27, 1961. See also note, Eugene E. Horton to Powers on MR–BD publicity and point of test in "wriggling" Redstone; message, Powers to Paul Haney, date missing.

[78] Of a total of 71 Redstone booster flights (including 4 Mercury-Redstone) through March 24, 1961, only 10, or 14.1 percent, were classed as failures by the latest revision of a composite document prepared under W. A. Mrazek, Director, Structures and Mechanics Division: "Redstone Vehicle Malfunction Study (Mercury-Redstone Program)," MSFC report No. DSD–TM–12–60, Rev. B, May 1, 1960, 8.

[79] See "Final Report: Mercury-Redstone Project Launch Operations," Appendix M; Ms., George F. Killmer, Jr., et al., "Mercury Technical History—Preflight Operations," Dec. 30, 1963, 85–90, Fig. 11; James M. Grimwood, *Project Mercury: A Chronology,* NASA SP–4001 (Washington, 1963), 131, 207, 218.

[80] Purser, log for Gilruth, April 10, 1961; Purser, interview, Houston, Feb. 12, 1964; Gilruth interview; Silverstein, interview, Cleveland, May 1, 1964; *Aeronautical and Astronautical Events of 1961,* 15. See also "Rumors Fly as Moscow Alerts Press," *Washington Post,* Apr. 11, 1961.

[81] Donald F. Hornig, chairman, "Report of the Ad Hoc Mercury Panel," Apr. 12, 1961, 18, passim. The membership of this panel included, in addition to Hornig, Paul Beeson, W. John Beil, Milton V. Clauser, Edward H. Heinemann, Lawrence S. Hyland, Donald P. Ling, Robert B. Livingston, Harrison A. Storms, and Cornelius Tobias. The two technical assistants were Douglas R. Lord and James B. Hartgering, and two special consultants were Alfred P. Fishman and Paul Wickham.

[82] *Ibid.* See also "Debate Reported Over Space Shot: Kerr Asserts Kennedy Aides Disputed Flight's Wisdom," *New York Times,* May 10, 1961; Lord interview. Mae Mills Link, *Space Medicine in Project Mercury,* NASA SP–4003 (Washington, 1965), treats at greater length some of these problems in her chapter VIII, entitled "The Season of Crisis: 1961," 112–125.

[83] For an overview of these issues, see chapter on "Gagarin" in Holmes, *America on the Moon,* 83–92; Thomas A. Reedy, "Britons Say Reds' Timing May Indicate 'Lie in Sky,'" Newport News *Daily Press,* April 13, 1961. Some question was also raised in Congress and the press whether Gagarin's flight was in fact a complete orbit, since it apparently fell short of its starting point by a few miles.

[84] Memo, Powers to Gilruth, "Pre-planned Comment for Possible Russian Space Shot," Sept. 27, 1960. All quotations are taken from House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *Discussion of Soviet Man-in-Space Shot,* 7, 11, 16, 18, 27, 33.

[85] It is widely believed that Yuri A. Gagarin rode all the way down to impact inside his capsule and that his flight was made fail-safe by the choice of a rather steep reentry trajectory. For pictorial comparisons of the Soviet spacecraft and booster systems, see the series of articles in *Aviation Week,* LXXXII (May 10, 1965), "Russia Displays Vostok with Spheri-

cal Cabin," 28–29; (May 17, 1965), "Soviets Unveil 3-Stage ICBM," 26–31; (May 24, 1965), "Photos of Vostok Display Reveal New Details of Spacecraft," 76–78; (May 31, 1965), "Photos Show Details of Cabin, Suit," 58–60; (June 7, 1965), "Gazenko Discusses Soviet Space Medicine," 40–45. Cf. memo, M. Scott Carpenter to Gilruth et al., "Cosmonaut Training," Nov. 24, 1964.

[86] These parameters are based on a 28-page typewritten translation by Joseph L. Zygielbaum from *Pravda,* April 25, 1961, entitled "The First Flight of Man into Cosmic Space," and circulated around STG as the best data then available. For comparative information, see Senate Committee on Aeronautical and Space Sciences, 87 Cong., 2 sess. (1962), *Soviet Space Programs: Organization, Plans, Goals, and International Implications,* Table I, 106–107, 108; and Charles S. Sheldon II, "The Challenge of International Competition," paper, the Third American Inst. of Aeronautics and Astronautics/NASA Manned Space Flight Meeting, Houston, Nov. 4–6, 1964, Table V, 26. See also Fédération Aéronautique Internationale, record claim.

[87] *Soviet Man in Space* (Moscow, [1961]), 93. See also Joseph L. Zygielbaum, "The Soviet Space Program," in the World Book Science Annual, *1965 Science Year* (Chicago, 1965), 64–75.

[88] Statement by Yuri A. Gagarin at the Soviet Scientist's Club reported April 16, 1961, in *The First Man in Space: The Record of Yuri Gagarin's Historic First Venture into Cosmic Space: A Collection of Translations from Soviet Press Reports* (New York, 1961), 41; the first quotation is taken from Y. Maksaryov, ed., *Technical Progress in the U.S.S.R., 1959–1965,* trans. David Skvirsky (Moscow, [1963]), 10.

[89] Newport News *Times-Herald,* April 13, 1961; statements of Glenn, Virgil I. Grissom, and Alan B. Shepard, Jr., April 12, 1961; statement of Gilruth, April 12, 1961; NASA News Release 61–80, April 20, 1961.

[90] House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), Report No. 391, to accompany H.R. 6874, *Authorizing Appropriations to the National Aeronautics and Space Administration,* testimony of Seamans, 360–382; *Aeronautical and Astronautical Events of 1961,* 11, 15; and Seamans, interview, Washington, Sept. 1, 1965. See also "Ups and Downs in Space as U.S. Gets Set to Launch Man," *Life,* L (May 5, 1961).

[91] Memos, North to Dir., Space Flight Programs, "Operational Considerations for MA–3," April 10, 1961; "Mission Change for MA–3," April 17, 1961; Williams, interview, Houston, Aug. 23, 1965; John P. Mayer, comments, Sept. 8, 1965.

[92] Memos, Silverstein to Assoc. Administrator, "Mission Change for Mercury-Atlas 3," April 18, 1961; Snyder to NASA Technical Personnel, Technical Information Center, "Mercury-Atlas 3 (MA–3) Launch," April 24, 1961; "R. J. W." for record, "MA–3 Flight Particulars," April 24, 1961; "Technical Information Summary of Mercury-Atlas Mission No. 3 (Capsule No. 8)," STG, April 17, 1961; "Mission Directive for MA–3," Project Mercury, Oct. 18, 1960, rev. March 31, 1961; "Calculated Pre-Flight Trajectory Data," NASA Project Mercury working paper No. 184, April 14, 1961; "Mercury Control Center Countdown Flight Control and Overall Operations MA–3," March 16, 1961; rev. April 20, 1961; "MA–3 Mission Rules—Correction Copy," undated. See also Huss comments.

[93] Memo, Low to Administrator, "Mercury Atlas 3 Launching," April 24, 1961; John H. Disher to Administrator, "Mercury-Atlas Flight No. 3," April 26, 1961; "Mercury-Atlas No. 3 (MA–3) Memorandum Report for the Project Director," STG, April 28, 1961. This realistic exercise for the launch site recovery team, as well as the beautiful performance of the escape tower, increased confidence in spite of the mission failure.

[94] Memo, Low to Dir., Space Flight Programs, "Atlas 100–D Programmer," June 12, 1961; Hohmann, "Atlas 100–D Investigation Board Status Report," June 14, 1961.

[95] "Mission Directive for Little Joe No. 5–B (Capsule No. 14)," NASA Project Mercury working paper No. 183, April 7, 1961; "Technical Information Summary of Little Joe No. 5–B," April 12, 1961; Alfred I. Alibrando and Horton, "Information Plan: Project Mercury Little Joe Seven," April 7, 1961; NASA News Release 61–82, "Project Mercury Escape System Test: Little Joe Seven," April 20, 1961. Low has commented that "if Little Joe 5B had failed, it might have put a constraint on MR–3 that would have prevented its launching."

[96] "Post-Launch Report for Mercury Little Joe Mission 5B (LJ–5B)," NASA Project Mercury working paper No. 195, June 12, 1961, 1–1, 2–1, passim. So far above the design limits for max- q on Little Joe was the performance of LJ–5B that this production capsule might have carried a man safely

after all if all other provisions had been developed: Williams interview.

[97] "Status Report No. 10 for Period Ending April 30, 1961," STG, was the tenth quarterly review of Project Mercury by the 700 or so members of STG for NASA Headquarters. Of six flights since January, only two (MA–3 and LJ–5A) were admitted failures. Of 10 qualification flight tests with production McDonnell capsules to date (the 4-inch flight of MR–1 was excluded), 6 (including MR–BD) were counted as "successful," although a historical accounting should, on the basis of intent, make that record read 5 out of 10 "unsuccessful" at least. Capsule orbit weight was calculated at 2836 pounds and expected to be 2874 pounds by July, still within Atlas capabilities. "Project Orbit," the simulated orbital test program using Capsule No. 10 in McDonnell's altitude chamber, was well underway; the tracking network and ground instrumentation system was reported 95 percent complete; while ground qualifications testing and reliability testing were said to be 95 and 90 percent complete, respectively. Readiness for the first manned sub-orbital test flight, including the lately renewed studies to "quick-fix" the impact protection, landing system, and reaction control system, and to test more animals in centrifuges, was asserted to be clear if the flight safety review board meetings at the Cape on April 28–29, 1961, should certify both capsule and booster.

## *Chapter XI*

[1] Letter, Larry Stoddard, Rating Section, National Broadcasting Company, Inc., to Sigman Byrd, Hist. and Library Services Br., MSC, March 15, 1965; "Postlaunch Report for Mercury Redstone No. 3 (MR–3)," NASA Project Mercury working paper No. 192, June 16, 1961, 73; James M. Grimwood, *Project Mercury: A Chronology,* NASA SP–4001 (Washington, 1963), 35, 124; "Postlaunch Trajectory Report for Mercury-Redstone Mission 3 (MR–3, Capsule 7)," NASA Project Mercury working paper No. 210, Oct. 12, 1961, 1–2.

[2] Tape of press conference, Mercury astronauts, Cape Canaveral, Feb. 22, 1961. At the conference Robert R. Gilruth pointed out that the four remaining astronauts were not eliminated, since there would be other flights. He said it was simply that at this point in the program a few had to be selected to participate in a particular mission, and that it was only practical to select those best prepared. The others would continue training. Nancy Lowe, secretary to the Mercury astronauts for more than four years, said in an interview with the authors on Feb. 27, 1964, that STG had been besieged for interviews only after the announcement that Shepard, Glenn, and Grissom had been selected to train for the first flight.

[3] Memo, George M. Low to Dir., Space Flight Programs, "Project Mercury Status," Jan. 6, 1961; memo, Warren J. North to Dir. of Space Flight Programs, "Mercury Status as of Jan. 13, 1961," Jan. 16, 1961; "Project Mercury Status Report No. 9 for Period Ending Jan. 31, 1961," 3.

[4] Alan B. Shepard, Jr., interview, Houston, Aug. 6, 1964.

[5] House Committee on Science and Astronautics, 87 Cong., 2 sess. (1962), *Aeronautical and Astronautical Events of 1961,* 7; "Individual Astronaut Monthly Training Schedules, Sept. 1960–Feb. 1961," undated; Donald K. Slayton, "Pilot Training and Preflight Preparation," in *Conference on Medical Results of the First U.S. Manned Suborbital Space Flight: A Compilation of Papers, NASA in Cooperation with National Institutes of Health and National Academy of Sciences* (Washington, 1961), 95.

[6] "Pilot Preparation for MR–3 Mission," undated; Carmault B. Jackson and Richard S. Johnston, "Astronaut Preparation and Activities Manual for MR–3," NASA/STG, Dec. 1, 1960.

[7] Memo, Sigurd A. Sjoberg, et al., Flight Operations Div., STG, to Assoc. Dir., "Astronaut Briefing and Debriefing for MR–3 Mission," April 4, 1961; letter, Walter C. Williams to Comdr., Air Force Missile Test Center, re personnel at Grand Bahama debriefing, April 26, 1961.

[8] NASA News Release 61–99, "Mercury-Redstone 3 Press Conference, Cape Canaveral," May 5, 1961; memo for files, Martin A. Byrnes, STG, "Recovery MR–3," May 11, 1961; "MR–3 Recovery Operations," anon., undated. R/A G. P. Koch directed recovery operations in the impact area. His supporting ships and their commanders were: carrier, *Champlain,* Capt. R. Weymouth; destroyers, *Decatur,* Cdr. A. W. McLane; *Wadleigh,* Lt. Cdr. D. W. Kelly; *Rooks,* Cdr. W. H. Patillo; *Sullivans,* Cdr. F. H. S. Hall; and *Abbott,* Cdr. R. J. Norman; and radar ship (DDR) *N. K. Perry,* Cdr. A. O. Roberts. The recovery force again included the P2V aircraft under Cdr. R. H. Casey, Jr.

## FOOTNOTES

[9] Letter, Williams to R/A F. V. H. Hilles, March 14, 1961; letter, Cdr., Air Force Missile Test Center, to Hilles, "Mercury Air-Ground Voice Relay and Real-Time Display in AMR Telemetry Aircraft," March 21, 1961.

[10] Message, [Cdr. DesFlotFour] to STG et al., April 19, 1961; memo, Sjoberg et al., to NASA Assoc. Dir., "MR–3 Postflight Debriefing of Alan B. Shepard," Aug. 22, 1961. As it turned out, the same helicopter pilot team (Marine Lts. Wayne E. Koons and George F. Cox) that practiced with the three astronauts in the special training team effected the water recovery of the first suborbital spaceman. Wayne E. Koons and James L. Lewis, interview, Houston, Sept. 16, 1965.

[11] Letter, F. W. Reichelderfer to T. Keith Glennan, June 9, 1960; memo, Williams to Maj. Gen. Leighton I. Davis, "Meteorological Support of Project Mercury," Aug. 31, 1960; Reichelderfer to Gilruth, April 18, 1961, with enclosure, "Status of Weather Support for Project Mercury, April 1961."

[12] "Operations Requirements No. 1904, Mercury-Redstone Launch," Feb. 15, 1961.

[13] Byrnes memo.

[14] Based on a series of interviews. Also see Mae M. Link, *Space Medicine in Project Mercury*, NASA SP–4003 (Washington, 1965), 112–125. See also p. 331 of this work.

[15] A. Duane Catterson, interview, Houston, April 10, 1964.

[16] Stanley C. White, Richard S. Johnston, and Gerard J. Pesman, "Review of Biomedical Systems Prior to the MR–3 Ballistic Flight," undated. Another criticism leveled by members of the PSAC panel in March 1961 was that the fire hazard in a pure oxygen atmosphere had not been sufficiently dealt with through tests. The subject had been considered by STG; the conclusion was that depressurization would serve as an excellent fire extinguisher. Robert B. Voas, interview, Houston, April 15, 1964. See also p. 287.

[17] Newport News *Times-Herald*, March 25, 1961; Shreveport *Times*, April 2, 1961. Howard I. Gibbons, then associated with the Newport News *Daily Press*, later of the Public Affairs Office, MSC, interviewed the seven astronauts on July 7, 1959, at a NASA Press Day event. The following Sunday, Gibbons predicted in the *Daily Press* that Alan Shepard would be the first astronaut in space. As far as can be determined, this was the first speculation in the matter. "It was just a good guess," said Gibbons.

[18] Voas interview.

[19] Shepard interview; Gilruth, interview, Houston, March 18, 1964.

[20] Memo, Public Affairs Officer, MSC, to Chief, Hist. and Library Services Br., March 11, 1964. There was some resistance to the publicity buildup. The painful experience of Dec. 6, 1957, when the public witnessed the spectacular launchpad failure of the Vanguard booster, America's first attempt to launch an artificial satellite, had not been forgotten. *Wall Street Journal*, May 2, 1961.

[21] *Washington Post*, May 3, 1961; *New York Times*, May 5, 1961; memos, John H. Disher, Head, Advanced Manned Systems, NASA, to Administrator, "Mercury-Redstone Launching," May 1, 1961, and May 4, 1961.

[22] *Chicago Tribune*, April 29 and 30, 1961; *Washington Daily News*, April 29, 1961; Washington *Evening Star*, April 29, 1961; *Washington Post*, May 1, 1961; Baltimore *Sun*, April 30, 1961; *New York Times*, May 2 and 3, 1961; Newport News *Times-Herald*, May 2, 1961; "Mercury Astronauts Work as a Team on MR–3," undated. A statement by Gilruth on the mode of pilot selection for MR–3 is contained in *NASA Fifth Semiannual Report to Congress, Oct. 1, 1960, through June 30, 1961* (Washington, 1962), 15, 17, 18.

[23] "NASA Note to Editors," April 24, 1961; *New York Times*, May 2, 1961.

[24] *Conference on Medical Results of the First U.S. Manned Sub-orbital Space Flight*, 7, 8; "Pilot Preparation for MR–3 Mission," anon., undated. Safety measures, including appropriate actions, covering each time segment of the second half of the split countdown were published just before the MR–3 mission in "Emergency Handbook for Pad Area Rescue, Mercury-Redstone, Capsule 7," May 2, 1961. This document later was revised and reissued on June 29, 1961, to cover Capsule 11 and the MR–4 flight.

[25] *Ibid.*; Sjoberg, April 4 memo; "Postlaunch Report for MR–3," 43–45. During the early part of the countdown on May 5, John Glenn, the backup pilot, spent considerable time in the spacecraft assisting in systems checkouts. To help relieve any tension Shepard might have built up, Glenn pasted a little sign on the spacecraft panel, reading "No handball playing here." This bit of levity hearkened back to their training days. Later he went to Mercury Control Center and stood behind Donald K. Slayton, spacecraft communicator, helping to gather data to feed to Shepard during the flight.

[26] "Postlaunch Report for MR–3," 45–46;

*Conference on Medical Results,* 8; memo, Henry E. Clements to Christopher C. Kraft, Jr., "Test 108, 4–5 May, 1961, Network Status Monitor Report," May 8, 1961; "Mercury Redstone 3 Press Conference"; memo, Disher to Administrator, "Mercury-Redstone Mission," undated. After four hours without relief and with only a primitive urine collection system, his underwear got wet, but the suit air regenerating system worked very well. Sjoberg, Aug. 22 memo; Lee McMillion, interview, Houston, Oct. 30, 1963; memo, Carl R. Huss to Flight Dir., "Record and Comments on Activities and Observations Made at Retrofire Controller's Position During Test 108 (MR–3)," May 5, 1961.

[27] "Postlaunch Report for MR–3"; *Conference on Medical Results of the First U.S. Manned Suborbital Space Flight,* 74; Shepard, speech, Society of Experimental Test Pilots, Los Angeles, Sept. 30, 1961; letter, John A. Powers to W. J. Phillippi, Aug. 4, 1961. As for the other astronauts, Carpenter and Grissom observed from the Mercury Control Center.

[28] Later, during postlaunch debriefings, Shepard stated that the decision to carry or eliminate the personal parachute on subsequent flights should be left for the prime pilot. An unidentified astronaut at the debriefing (probably Schirra) exclaimed, "Please!"

[29] The "Kennedy call" was to become a standing event in all manned Mercury flights.

[30] Shepard gave a most lucid account of his mission from liftoff to water impact, following his preliminary medical examination aboard the *Champlain.* Shepard's dictated report is contained in "Postlaunch Report for MR–3," and in the Sjoberg debriefing memo of Aug. 22. The latter document also gives questions by the debriefers and answers by the astronaut covering every aspect of the flight. Also see "Shepard and USA Feel A. OK," *Life,* L (May 12, 1961); Alan B. Shepard, Jr., "Astronaut's Story of the Thrust into Space," *Life,* L (May 19, 1961).

[31] "Postlaunch Report for MR–3"; memo, Morton Schler to Kraft, "Postlaunch Summary Report of MR–3 Mission," May 5, 1961; Byrnes memo; Sjoberg, Aug. 22 memo.

[32] *Ibid.;* memo, Slayton to Flight Dir., "MR–3 Mission Report," May 15, 1961. The ships did have a communications problem during spacecraft descent, however, because of background interference from Latin-American broadcasting stations.

[33] Memo, Gilruth to staff, "Congratulatory Messages in Regard to MR–3 Flight," June 17, 1961.

[34] "Documentation of the First Manned Space Flight without Earth Orbit by the United States of America," National Aeronautic Assn., United States Representative, Fédération Aéronautique Internationale, Washington, 1961. Shepard submitted certification of his flight on May 15, 1961. Regarding contrasts between reports of the Shepard and Gagarin flights, cf. *The First Man in Space: The Record of Yuri Gagarin's Historic First Venture into Cosmic Space,* trans. from Soviet press reports (New York, 1961). A large portion of the text is political propaganda. A photograph of the launch is obscured in clouds of smoke—much as the whole program was. The Shepard flight was reported in words and pictures without allusion to political ideology. The report of the Turkish journalists was extracted from *Aeronautical and Astronautical Events of 1961,* 24.

[35] White House News Release, "John F. Kennedy, President of the United States, Special Message to Congress, May 25, 1961." *Freedom 7* was displayed publicly at Cape Canaveral beginning on May 20, 1961, the day the launch area was first opened to the public.

[36] For fiscal data on the fiscal year 1962 program, see House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *1962 NASA Authorization, Hearings;* Senate Subcommittee of the Committee on Appropriations, 87 Cong., 1 sess. (1961), *Independent Offices Appropriations, 1962, Hearings;* House Committee on Science and Astronautics, 87 Cong., 1 sess. (1961), *Authorizing Appropriations to the National Aeronautics and Space Administration,* 28–38.

[37] *Mercury Project Summary, Including Results of the Fourth Manned Orbital Flight, May 15 and 16, 1963,* NASA SP–45 (Washington, 1963), 1. This report says more than 2,000,000 people from government, industry, and institutions were involved in Project Mercury. For the components alone there were some 10,000 contractors, subcontractors, and suppliers. The Public Affairs Office of the Manned Spacecraft Center said that the Apollo program had about 40,000 contractors and suppliers as of May 1964. See also Tom Alexander, *Project Apollo: Man to the Moon* (New York, 1964), 8.

[38] Memos, H. Kurt Strass to Chief, Flight Systems, STG, "Activation of Study Program Pertaining to Advanced Manned Space Projects," June 22, 1959; "First Meeting of New

Project Panel, Wednesday, Aug. 12, 1959," Aug. 17, 1959; and "Third Meeting of New Projects Panel, Monday, Sept. 28, 1959," Oct. 1, 1959; memos, Gilruth to staff, "Advanced Vehicle Team," May 25, 1960; "Change in Organization of the Space Task Group," Sept. 1, 1960; and "President's Request for Additional Budget Action," May 26, 1961. A NASA-sponsored "Conference on the Peaceful Uses of Space" was also meeting at this time in Tulsa.

[39] "Manned Spacecraft Development Center, Organizational Concepts and Staffing Requirements," May 1, 1961. Some 13 days before the Presidential pronouncement, a House appropriations authorization document foresaw an increased personnel requirement for STG, estimating the need at about 300 additional people. Moreover, it was noted that the organization would be carried as a separate research center for financial allocation purposes, beginning with fiscal 1962, although STG's work was then domiciled at the Langley Research Center and divided between Langley, Goddard, and the Cape. STG's personnel strength reached 1152 by the end of 1961, and it had proposed some 3000 personnel spaces in the May study for a Manned Spacecraft Development Center. *Authorizing Appropriations to NASA,* 6.

[40] Newport News *Times-Herald,* May 30, 1961; Newport News *Daily Press,* May 30, 1961; *Aeronautical and Astronautical Events of 1961;* memo, Paul E. Purser to Gilruth, "Log for Week of Aug. 7, 1961," Aug. 15, 1961. Besides speculating about the move, the press now began acquainting the public with the new manned space projects. What later became Project Gemini was described, and the lunar program was discussed. The estimated cost of these activities was mentioned frequently. (See *Washington Post,* May 24 and 26, 1961; *New York Times,* May 24 and 26, 1961; Baltimore *Sun,* May 26, 1961.) A cartoon by Herblock, of the *Washington Post,* pictured a a launch vehicle and a spacecraft waiting on the pad while the pilot (President Kennedy) walked toward a service station and ordered an attendant (Congress) standing by a fuel pump, "Fill 'er up—I'm in a race."

[41] Virgil I. Grissom, interview, Houston, April 12, 1965; "Postlaunch Memorandum Report for Mercury-Redstone No. 4 (MR-4)," Aug. 6, 1961. During his debriefing Grissom complained about having to travel so much for training missions. He suggested that an ALFA trainer be installed at Cape Canaveral.

[42] Excerpts from messages compiled by Purser; Morton J. Stoller, "Some Results of NASA Space Flight Programs in 1960–61," paper, Third International Symposium on Rockets and Astronautics, Tokyo, 1961.

[43] *Results of the Second U.S. Manned Suborbital Space Flight, July 21, 1961* (Washington, 1961), 4; "Postlaunch Memorandum Report for MR-4"; "Astronaut Recovery Handbook (Capsules No. 11 and 15)," McDonnell Aircraft Corp., St. Louis, June 1, 1961.

[44] "MR-4 Press Kit," June 29, 1961; *Results of the Second U.S. Manned Suborbital Flight,* 3, 4. The window measured 19 inches high, 11 inches across the base, and 7½ inches across the top. NASA News Release 61–152, "MR-4 Design Changes," July 16, 1961. The contract change proposal providing for the observation window was submitted in October, 1959. Memo, Purser to Langley Research Center, "Contract NAS 5–59; Contract Change Proposal No. 73, Astronaut Observation Window Installation," Oct. 1, 1959.

[45] "Postlaunch Memorandum Report for MR-4"; memo, Future Projects Br., Aeroballistics Div., Marshall Space Flight Center, "Project Mercury-Redstone: Additional Trajectory Data for MR-4," June 3, 1961.

[46] Newport News *Daily Press,* July 16, 1961. Someone had done Grissom the favor of painting a likeness of the crack in the original Liberty Bell on spacecraft No. 11. Other astronaut assignments for the MR-4 mission put Shepard and Schirra in the Mercury Control Center, the former as "Cap Com," the latter as observer; Slayton and Carpenter in the blockhouse; and Cooper flying the chase plane.

[47] "Postlaunch Memorandum Report for MR-4"; memo, Sjoberg to Assoc. Dir., "MR-4 Postflight Debriefing of Virgil I. Grissom," undated. Grissom became chilled while waiting in the spacecraft for launch on Wednesday, July 19. His suit inlet temperature was about 61 degrees F. On the day of the flight, the suit inlet temperature (55 degrees F) was more comfortable because the astronaut's underclothing remained essentially dry. Reception of medical data from Grissom's flight was better than that from Shepard's.

[48] "MR-4 Design Changes," 61–152.

[49] Grimwood, *Mercury Chronology,* 214; "Postlaunch Memorandum Report for MR-4"; "MR-4 Press Kit"; memo, Low to NASA Administrator, "Mercury-Redstone-4 Launching," July 17, 1961. The recovery forces were deployed in the same manner as for

Ham and Shepard. Under direction of R/A J. L. Chew, stationed in Mercury Control Center as an advisor to Williams, the main forces consisted of an aircraft carrier, three destroyers, and two destroyer escorts. Five P2V aircraft, supplemented by Air Rescue Service planes, provided contingency recovery support. Carrier and shore-based helicopters were assigned to pick up the spacecraft, while just off Cape Canaveral a rescue salvage vessel stood by for action in the event of a mission abort. And, once again, land vehicles were deployed around the launch site for duty in case of a catastrophe.

[50] Memo for news media representatives, July 16, 1961; Virgil I. Grissom, "The Trouble with Liberty Bell," in John Dille, ed., *We Seven, by the Astronauts Themselves* (New York, 1962), 216–219.

[51] "Postlaunch Memorandum Report for MR–4."

[52] Dille, ed., *We Seven,* 217–218.

[53] The count was resumed, but after another 15 minutes a 9-minute hold was called for turning off pad-area searchlights—which in the past had caused telemetry interference.

Next came a 41-minute hold because cloudy skies had reduced light conditions to below par for camera coverage. During this hold, the main inverter began to overheat, reaching 190 degrees F, and so Grissom switched to the standby unit to allow the main component to cool. When the count resumed at 15 minutes before launch, he switched back to the main inverter. Significantly, during the 80 extra minutes from astronaut insertion to liftoff, not one of the holds was chargeable to the booster. Sjoberg undated memo; "Postlaunch Memorandum Report for MR–4."

In an interview with Grissom on April 12, 1965, the pilot stated that the misaligned bolt had nothing to do with the premature explosion of the hatch. In fact, if a number of bolts were misaligned it would be unlikely that the hatch would blow off at all. Grissom now has the misaligned bolt as a souvenir.

[54] The following detailed account of Grissom's flight is based, like that for Shepard, on the evidence of the motion picture camera, the tape transcript of communications, the confidential postflight report, the debriefing records, telemetry transcripts, and personal interviews.

[55] The rate control system consumed about 3½ pounds of hydrogen peroxide in 2 minutes. Based on this usage, if that system were used exclusively during an orbital mission, all of the control fuel would be expended in 20 minutes. Grissom's automatic stabilization and control system worked so slowly during turnaround because, as a later review team discovered, the one-pound rate thrusters contained some decomposed material.

[56] "Postlaunch Memorandum Report for MR–4"; Sjoberg undated memo; *Results of the Second U.S. Manned Suborbital Flight;* "Project Mercury Status Report No. 11 for Period Ending July 31, 1961," NASA/STG, 7–9, 26, 30, 31; memo, Richard J. Wisniewski to NASA Administrator, "Mercury-Redstone-4 Mission," July 24, 1961; memo, John H. Dabbs, to Chief, Flight Operations Div., STG, "Mercury-Redstone-Four High Frequency Air/Ground Communications Test," Aug. 23, 1961; tape of press conference, Cocoa Beach, Fla., July 22, 1961. Participating with Grissom were James E. Webb, who awarded the astronaut the NASA Distinguished Service Medal; Leighton I. Davis; Eberhard F. W. Rees; Robert R. Gilruth; Walter C. Williams; William K. Douglas; Alan B. Shepard, Jr., and John H. Glenn, Jr. For Grissom's personal account of the mission, see Dille, ed., *We Seven,* 205–231. Most of the reports attribute Grissom's sinking lower in the water during the recovery period to the open suit inlet valve. The astronaut felt that the loss of buoyancy was caused by the neck dam. He based his belief on the fact that the dam had been in a rolled position for some five days; tests conducted later disclosed that the rolled rubber sets in two days' time, causing a loss of airtight integrity. Virgil I. Grissom, interview, Houston, April 12, 1965. Also see Virgil I. Grissom, "It was a Good Flight and a Great Float," *Life,* LI (July 28, 1961), and Grissom, "Hero Admits He Was Scared," *Life,* LI (July 28, 1961).

[57] Memo, North to Assoc. Administrator, "Status of MR–4 Hatch Investigation," Aug. 30, 1961; "Postlaunch Memorandum Report for MR–4." Carpenter, after the second orbital flight, was retrieved from his raft, being the only other Mercury astronaut to ride a helicopter to a ship. He, too, was dunked by swells before he was airborne. Grissom expressed his opinion in an interview on April 12, 1965, that he believed the premature hatch explosion was caused by the exterior lanyard being loose. At that time it was held in place by only one screw. Subsequently a better method of securing the lanyard was effected.

[58] Gherman Titov, *700,000 Kilometres Through Space: Notes by Soviet Cosmonaut No. 2* (Moscow [1962]); Titov and Martin

Caidin, *I Am Eagle!* (Indianapolis, 1962), based on interviews with Wilfred Burchett and Anthony Purdy.

[59] For three final reports on the Mercury-Redstone program, see "Final Report Mercury Redstone Project Launch Operation," Marshall Space Flight Center, May 28, 1962; "The Mercury-Redstone Project," MSFC Saturn/Apollo Systems Office, June 1964; and Jerome B. Hammack and Jack C. Heberlig, "The Mercury-Redstone Program," paper No. 2238–61, read before American Rocket Society, Oct. 9–15, 1961. See also memo, North to Deputy Dir., Space Flight Programs, NASA Hq., "Mercury Status Items for Project Review Meeting, June 27, 1961," June 22, 1961.

[60] Purser, Aug. 15 memo; memo, Gilruth to Silverstein, "Recommendations on MR–5 Flight," undated; *Aeronautical and Astronautical Events of 1961,* 40; memo, Joachim P. Kuettner to Eberhard Rees et al., "Final Disposition of Mercury-Redstone Project," Aug. 24, 1961; David S. Akens, Paul K. Freiwirth, and Helen T. Wells, *History of the George C. Marshall Space Flight Center* (Huntsville, Ala., 1960–1962), 7, 19. In an interview on April 12, 1965, Grissom stated that some of the astronauts wanted to proceed with MR–5 because the launch vehicle and spacecraft were about ready.

[61] Titov, *700,000 Kilometres Through Space,* 60–79, 91–124; Titov and Caidin, *I Am Eagle!* 166–200; Pavel Barashev and Yuri Dokuchayev, *Gherman Titov: First Man to Spend a Day in Space* (New York, 1962), 93–102; Newport News *Daily Press,* Aug. 9, 1961.

[62] Stuart Symington, "Why We Lag in Space," speech, U.S. Senate, June 26, 1961; John W. Finney, "Capital Worried by Lags in Plans on Race to Moon," *New York Times,* Aug. 13, 1961; Vern Haugland, "NASA Hopes to Put Mercury Astronaut in Orbit by Next December or January," Newport News *Times-Herald,* Aug. 7, 1961.

## *Chapter XII*

[1] Message, Walter C. Williams to Cdr., DesFlotFour, Dec. 8, 1960; "Project Mercury Status Report No. 9 for Period Ending Jan. 31, 1961," 40, 41, 43; Paul E. Purser, log for Robert R. Gilruth, April 17, 1961; "Project Mercury Status Report No. 10 for Period Ending April 30, 1961," 33. For a complete discussion of the MA–3 mission, see pp. 335–337. Counting MA–4 as the fifth Mercury-Atlas combination launched includes Big Joe.

[2] "Status Report No. 10," 33; James M. Grimwood, *Project Mercury, A Chronology,* NASA SP–4001 (Washington, 1963), 214; "Project Mercury Postlaunch Report for Mercury-Atlas Mission 4 (MA–4, Capsule 8A)," NASA Project Mercury working paper No. 213, Nov. 10, 1961.

[3] *Ibid.;* message, NASA Hq. to STG, Aug. 25, 1961; memo, Morton Schler to Flight Dir., "Report on Test 1254," Oct. 3, 1961; Walter C. Williams, interview, Houston, Aug. 23, 1965; Bernhard A. Hohmann, interview, Houston, Sept. 16, 1965; memo, P. I. Harr, GD/A, to Members of Astronautics Reliability Policy Committee, "Minutes of Special 28 August 1961 Meeting on Transistors," Aug. 29, 1961.

[4] "Project Mercury Status Report No. 11 for Period Ending July 31, 1961," 11, 12. As finally configured, Atlas No. 88–D had modifications in the sustainer engine liquid oxygen duct to improve performance, and the first four panels of the upper liquid oxygen tank area were of "thick-skin" materials designed to support high aerodynamic loads. "Postlaunch Report for MA–4." Moreover, a three-second hold-down was programmed for MA–4. Tests conducted by the Rocketdyne Division, North American Aviation, indicated that a two-second hold-down was adequate for Mercury-modified Atlas engines. So for flights beginning with MA–5, STG officials planned to institute the two-second procedure.

[5] NASA News Release 61–182, "Mercury-Atlas 4," Aug. 20, 1961; "Project Mercury Technical Information Summary of Mercury-Atlas Mission No. 4/8A (Capsule No. 8A)," NASA/STG, July 21, 1961. The Mercury ground tracking communications network at this time had 140,000 actual circuit miles, consisting of 100,000 miles of the teletype circuits, 35,000 of telephone circuits, and 5000 of high-speed telemetry circuits.

[6] "Pre-release Draft on Launch Vehicle (MA–4)," STG, undated; "Mercury-Atlas 4"; "Project Mercury Calculated Preflight Trajectory Data for Mercury-Atlas Mission No. 4 (MA–4) (Capsule No. 8A, Atlas No. 88–D)," NASA Project Mercury working paper No. 204, Aug. 2, 1961. The nominal launch trajectory was computed by the Aerospace Corp. and Space Technology Labs. under the technical direction of the Space Task Group. The abort sensing and implementation system continued monitoring during the entire powered phase. If trouble developed,

the clamp-ring released and posigrade rockets fired to separate the spacecraft, and the recovery gear was ready for action. Provided the powered flight phase went well, by about five minutes after launch the radio-inertial guidance system would be measuring speed, altitude, and flight course. If those factors anticipated a successful orbital insertion, the ground guidance computer, in operation shortly after booster engine cutoff, would initiate the shut-down command to the sustainer engine.

[7] "Project Mercury Mission Directive for Mercury-Atlas No. 4 (Capsule No. 8A)," NASA Project Mercury working paper No. 203, July 28, 1961; "Project Mercury Addendum Data Report for Mercury-Atlas Mission 4 (MA–4, Capsule 8A)," NASA Project Mercury working paper No. 218, Nov. 29, 1961.

[8] "Preflight Trajectory Data for MA–4."

[9] Letter, Williams, STG, to Cdr., DesFlot-Four, June 8, 1961, with enclosure, "Project Mercury, Mercury-Atlas No. 4 Recovery Requirements." The recovery forces consisted of 8 destroyers, 12 aircraft, a landing ship dock, and a utility vessel. Williams also stipulated secondary-zone recovery requirements and called for a nine-hour watch. In plotting contingency recovery areas, STG's planners had to allow for trajectory alteration resulting from the added thrust of escape rockets or retrofire in an abort.

[10] Williams letter; "Mission Directive for MA–4." William T. Lauten, Jr., said of the sofar bombs that during the program they jokingly referred to one as the sofar bomb and to the other, which was set to detonate several thousand feet beneath the waves, as the "so-long bomb."

[11] "Storms Hit 2 Mercury Trackers," Newport News *Times-Herald*, Sept. 12, 1961; "Postlaunch Report for MA–4"; Williams, interview.

[12] Memo, Carl R. Huss to Flight Dir., "Postlaunch Report on Test 1254," Sept. 15, 1961; Purser, penciled notes on MA–4 countdown and flight, Sept. 13, 1961; memo, Walter J. Kapryan, Capsule Systems Monitor, to Flight Dir., "Report on Test 1254," Sept. 29, 1961; memo, Tecwyn Roberts to Flight Dir., "Report on Test 1254," Sept. 25, 1961. Countdown procedures for MA–4 resembled those of the Mercury-Redstone missions. They were conducted in a 500-minute split-count with a 12- to 14-hour hold at T minus 300 for peroxide and pyrotechnics servicing. When the MA–4 count began Sept. 12 the operations crew feared that hurricane "Debbie" might adversely affect the recovery area, but the count proceeded to T minus 300. At 4 p.m. a weather review found conditions improving, so hydrogen peroxide servicing was begun. The count resumed at 2 a.m., Sept. 13. Weather reviews and a peroxide check, plus the problems described in the text, accounted for holds totaling 2 hours and 4 minutes during countdown.

[13] "Postlaunch Report for MA–4"; Kapryan memo.

[14] Memo, unsigned, to Flight Dir., "Verbal Debriefing at End of Flight—Test 1254," Sept. 13, 1961; Purser notes; Schler memo. The crewman simulator was a gray box, 24 by 12 by 8 inches, which took oxygen out of the environmental control system, emitted carbon dioxide, simulated minor suit leakage of oxygen, and initiated dumping. NASA News Release 61–206, "News Conference, Mercury-Atlas No. 4," Sept. 13, 1961.

[15] Purser notes; "Project Mercury Status Report No. 12 for Period Ending October 31, 1961," undated; Roberts memo; memo, Network Control Group to Flight Dir., "Network Control Group (NCG) Report on Test 1254," undated; memo, Alan B. Shepard to Flight Dir., "Report on Test 1254," undated; "Postlaunch Report for MA–4." During the mission several Mercury astronauts deployed to some of the remote tracking stations; Carpenter to Muchea, Australia; Cooper to Point Arguello, Calif.; Schirra to Guaymas, Mexico; Slayton to Bermuda. Glenn, Grissom, and Shepard were in the control center at Cape Canaveral, with Shepard serving as Capsule Communicator. (Message, STG to NASA Hq., Sept. 9, 1961.) This was the first time that the automatic stabilization and control system, the reaction control system, and the horizon scanner subsystem could be fully evaluated for orbital missions. The mission proved that the attitude control system was adequate for reentry.

[16] Kapryan memo; Purser notes; memo, George M. Low to NASA Administrator, "Preliminary Results of MA–4 Flight," Sept. 15, 1961. R/A John L. Chew, commanding Destroyer Flotilla Four, said at the Cape press conference following the flight that the seas were running only about a foot high in the recovery area—which meant that hurricane Debbie was ineffective in those waters. During the spacecraft's descent, a C–54 aircraft sighted its reentry contrails, shortly thereafter noted deployment of the main parachute, and

finally observed water impact. Pickup by the destroyer *Decatur* was effected at 12:15 p.m. The main chute and the antenna fairing were retrieved about 1000 yards from the spacecraft. All spacecraft recovery aids performed well with the exception of the radar chaff. "Post-launch Report for MA–4."

[17] "Status Report No. 12."

[18] Kapryan memo; Purser notes; Low memo.

[19] "News Conference, Mercury-Atlas No. 4." The principals at the news conference included Gilruth, Williams, R/A Chew, Col. R. S. Maloney, Col. Paul R. Wignall, Astronaut Virgil I. Grissom, and John A. Powers.

[20] Grimwood, *Mercury Chronology*, 147; NASA News Release 61–207, "Manned Space Flight Laboratory Location," undated; memo, Gilruth to staff, "Location of New Site for Space Task Group," Sept. 19, 1961. The team had surveyed sites in Tampa and Jacksonville, Fla.; New Orleans, Baton Rouge, Bogalusa, and Shreveport, La.; Houston, Beaumont, Corpus Christi, Victoria, Liberty, and Harlingen, Tex.; St. Louis, Mo.; Los Angeles, Berkeley, San Diego, Richmond, Moffett Field, and San Francisco, Calif.; and Boston, Mass. I. Edward Campagna, interview, Houston, June 16, 1963; "Manned Spacecraft Center," NASA/MSC brochure, June 1964. The Humble Oil and Refining Co. detached two tracts from acreage formerly operated as the Clear Lake Ranch and donated them to Rice University. Tract No. 1, consisting of 600 acres, was bought by the Government for $1,400,000. Tract No. 2, of 1020 acres, was donated to the Government, the tracts being transferred simultaneously. J. Wallace Ould, Chief Legal Counsel, MSC, interview, Houston, Sept. 24, 1964.

[21] "Manned Space Flight Laboratory Location"; Robert L. Rosholt, *An Administrative History of NASA, 1958–1963*, NASA SP–4101 (Washington, 1966); Stephen B. Oates, "NASA's Manned Spacecraft Center at Houston, Texas," *Southwestern Historical Quarterly*, LXVII (Jan. 1964). An editorial, "A Long View of What We Lost," in the Newport News *Daily Press*, of Oct. 3, 1961, reflects the public sentiment on the Virginia peninsula on the announced departure of the Space Task Group.

[22] *Houston Chronicle*, Oct. 11, 1961.

[23] *Houston Chronicle, Houston Post, Houston Press*, Sept. 21, 1961; "Manned Spacecraft Center Has Moved to Houston," NASA/MSC brochure, Aug. 1962. Activities of the new spacecraft center were housed in temporary facilities: Farnsworth and Chambers Building, Site 2, headquarters; Rich Building, Site 3, Spacecraft Research Division and Systems Evaluation and Development Division; Lane-Wells Building, Site 4, Life Systems Division; Houston Petroleum Center and Stahl and Meyers Building, Site 5, Project Mercury, Gemini, Apollo, and Flight Operations Division; East End State Bank Building, Site 6, Personnel and Security Divisions; Office City, Site 7, Flight Crew Operations Division; Ellington Air Force Base, Site 8, Procurement, Financial Management, Photographic Services and Supply; Minneapolis-Honeywell Building, Site 9, Public Affairs Office; Canada Dry Building, Site 10, Technical Services Division; KHOU–TV Building, Site 11, Data Computation and Reduction Division; Peachy Building, Site 12, Facilities Division. Later on, the center occupied additional temporary quarters in the Franklin Development Center and in a building formerly occupied by the Veterans Administration, and these became sites 13 and 14. The designation Site 1 was given to the Clear Lake site. "Manned Spacecraft Center Interim Facilities," NASA/MSC brochure, Aug. 15, 1963.

[24] "Houston Relocation Office Opens," Newport News *Times-Herald*, Sept. 27, 1961; memos, Wesley L. Hjornevik to staff, "Relocation Information Center," Oct. 5, 1961, and "Procedure for a Permanent Change of Duty Station," Nov. 1, 1961; memo, W. Kemble Johnson (Relocation Supervisor), to staff, "Relocation Plans," Oct. 18, 1961; memo, Purser to staff, "Designation of STG as 'Manned Spacecraft Center,'" Nov. 1, 1961; memo, unsigned, "Manned Spacecraft Center Building Facilities Requirements," Oct. 13, 1961.

[25] Purser, log for Gilruth, May 15, 1961; Grimwood, *Mercury Chronology*, 129.

[26] Memo, G. Barry Graves to those concerned, "May 16, 1961, Discussion of Proposed Scout Orbital Launch from Cape Canaveral," May 17, 1961. James T. Rose, interview, St. Louis, April 13, 1966.

[27] Memo, Purser to Gilruth, "Meeting on Proposed Scout Range Test," May 18, 1961. Those attending the meeting, held May 17, decided the flight should be scheduled for August.

[28] Purser, log for Gilruth, June 1, 1961; memo, Abe Silverstein to Robert C. Seamans, Jr., "Use of Blue Scout for Checkout of Mercury Network," May 24, 1961. Because of technical difficulties, the Mercury-Scout cost was about three times the $130,000 estimated

by Silverstein. William M. Bland, Jr., interview, Houston, Sept. 3, 1964.

[29] Memo, Purser to Warren J. North, "Details of the Mercury-Scout Instrumentation and Communication System," June 13, 1961; memo, Low to Gilruth and Williams, "Mercury Scout Test," June 22, 1961; memo, North to Deputy Dir., Space Flight Programs, NASA, "Mercury Status Items for Project Review Meeting—June 27, 1961," June 27, 1961.

[30] "Project Mercury, Summary of Calculated Preflight Trajectory Data for the Mercury Network Test Vehicle, MNTV–1," NASA Project Mercury working paper No. 200, July 12, 1961; "Project Mercury Mission Directive for Mercury-Scout Mission No. 1 (MS–1)," NASA Project Mercury working paper No. 201, July 21, 1961. The formal objectives of the Mercury-Scout mission were: (1) test real-time orbital computing capability at Goddard; (2) check out radar digital system and flow of digital data to the computer; (3) tailor the computation to the quality of data received by radar; (4) determine any interference that might exist between communications and data traffic; (5) determine the extent of system errors at radar sites, e.g., antenna misalignment, possible errors of surveyed position; (6) evaluate the updated radar procedures and revise as necessary; and (7) evaluate telemetry signal reception and operation of acquisition aids. "Status Report No. 11," 20.

[31] "Preflight Trajectory Data for the Mercury Test Vehicle, MNTV–1"; "Mission Directive for Mercury-Scout Mission No. 1."

[32] "Status Report No. 12," 21–22; "Status Report No. 11," 21; memo, Williams to Low, "Qualification Tests on Mercury-Scout Payload," July 24, 1961; memo, Low to D. Brainerd Holmes, "Dynamic Checkout of the Mercury Ground Network with Mercury-Scout," Nov. 8, 1961.

[33] "Project Mercury Status Report No. 13 for Period Ending Jan. 31, 1962," NASA/STG. According to the agreement with the Air Force, a launch team from that service was to be used. Letter, Williams to Air Force Systems Command, "Mercury Network Test Vehicle," July 7, 1961; Williams interview.

[34] Low memo. Some nine days after the failure of the Mercury-Scout-1, a one-and-a-half-pound squirrel monkey named Goliath was lost in an Air Force Atlas launching mishap. Thirty-five seconds after the rocket roared skyward, an explosion destroyed the tiny occupant of a small aluminum cylinder in the nose cone. Some newsmen, questioning the wisdom of the upcoming Mercury-Atlas chimpanzee launch, felt that this was a bad augury. But the Air Force Atlas had been an advanced E model, with modifications whose reliability was unproved, while the D model used in Project Mercury had been through its reliability program. So, Goliath notwithstanding, there was no change of plans. *Baytown* (Texas) *Sun,* Nov. 10, 1961; *Houston Chronicle,* Nov. 17, 1961.

[35] *Washington Post,* Nov. 19, 1961; *Houston Chronicle,* Nov. 12, 1961. Even members of Congress began publicly speculating on the date of the manned flight. Rep. Olin E. Teague told an audience at Texas Agricultural and Mechanical College that he understood the tentative date was Dec. 6. Rep. Victor L. Anfuso predicted the flight would go on Dec. 20. Newport News *Daily Press,* Oct. 25, 1961; *Washington Post,* Dec. 3, 1961.

[36] Purser, log for Gilruth, Sept. 13, 1961; Washington *Evening Star,* Nov. 19 and 28, 1961.

[37] David S. Akens et al., *History of the George C. Marshall Space Flight Center* (Huntsville, Ala., 1960–1962), I, 25–26; *Houston Post,* Oct. 22, 1961.

[38] "Status Report No. 9"; memo, Low to Assoc. Administrator, "MA–5 Launch Schedule," Oct. 18, 1961.

[39] "Status Report No. 11"; Low memo.

[40] "Postlaunch Memorandum Report for Mercury-Atlas No. 5 (MA–5)," NASA/MSC, Dec. 6, 1961; "Project Mercury Mission Directive for Mercury-Atlas 5 (Capsule 9)," Project Mercury working paper No. 208, Oct. 20, 1961.

[41] *Ibid.;* "Project Mercury, Mercury-Atlas No. 5 Recovery Requirements," NASA/STG, Oct. 5, 1961; "Detailed Test Objectives for NASA Mission MA–5," Aerospace Corp., Aug. 31, 1961. Objectives of MA–5 were (1) demonstrate spacecraft structural integrity, including that of ablation shield and afterbody shingles, (2) evaluate spacecraft systems performance during flight, (3) determine reentry motion, (4) determine vibration levels, (5) demonstrate launch vehicle and spacecraft compatibility, (6) demonstrate life-support capability in a three-orbit mission, (7) evaluate abort sensing and implementation system, (8) demonstrate capability of ground command control equipment, (9) evaluate network acquisition aids, and (10) evaluate telemetry performance. "Mission Directive for MA–5."

[42] "Mercury-Atlas No. 5 Recovery Requirements."

## FOOTNOTES

[43] "Status Report No. 11"; Low memo; "Detailed Test Objectives for MA–5."

[44] "Project Mercury Calculated Preflight Trajectory Data for Mercury-Atlas Mission 5 (MA–5) (Capsule 9—Atlas 93–D)," Project Mercury working paper No. 207, Oct. 19, 1961. The Atlas rocket was tracked through five orbits. On the fourth the perigee was 93 miles and the apogee 118 miles. "Postlaunch Memorandum Report for Mercury-Atlas No. 5."

[45] "Mission Directive for MA–5." Before his arrival at the Cape, Enos had received 1263 hours of training over a 16-month period, including 343 hours under restraint. *Results of the Project Mercury Ballistic and Orbital Chimpanzee Flights,* NASA SP–39 (Washington, 1963), 39.

[46] Norman E. Stingely and John D. Mosely, "MA–5 Operations," in *Results of the Mercury Chimpanzee Flights,* 35; Jerry Fineg, interview, Holloman AFB, Sept. 15 and 25, 1964; *Huntsville* (Ala.) *Times,* Nov. 29, 1961; Washington *Evening Star,* Dec. 1, 1961; *New York Times,* Nov. 30, 1961; *Houston Chronicle,* Nov. 12, 1961. The intelligence of these chimpanzees was remarkable. One of their training tasks was to pull a lever exactly 50 times, and for his accuracy the animal received a reward of a banana pellet. More or less than 50 pulls caused the training unit to recycle without giving any reward. Stanley C. White of MSC medical operations told a reporter that the chimps would pull the lever "bangity-bangity-bang" about 45 times, then carefully pull Nos. 46, 47, 48, and 49, and finally make pull No. 50 with one hand cupped under the dispenser to receive the reward. (Washington *Evening Star,* Nov. 28, 1961.) In a training test at Holloman a chimp working on a flashing-light problem pulled levers 7000 times in 70 minutes, making only 28 errors. Kenneth F. Weaver, "School for Space Monkeys," in "Countdown for Space," *National Geographic,* reprinted from the May 1961 magazine, 727. Also see article in *Aerospace,* XXXIV (March 1963).

[47] "Postlaunch Memorandum Report for Mercury-Atlas No. 5."

[48] "MA–5 Data Acquisition Plan," NASA/STG, Oct. 20, 1961.

[49] "Mercury Personnel Man Worldwide Tracking Sites During MA–5 Mission," anon., NASA/STG, undated; "Status Report No. 12"; "MA–5 Plan," anon., undated.

[50] "Postlaunch Memorandum Report for Mercury-Atlas No. 5."

[51] William Hines in the Washington *Evening Star* for Nov. 19, 1961, said it would be virtually impossible for the United States to make a manned orbital flight in 1961. On the other side, presenting an optimistic view, see Edward H. Kolcum, "Chimp Shot Raises Hope that U.S. Can Orbit Man Before Year's End," *Aviation Week,* LXXV (Dec. 4, 1961).

[52] "Postlaunch Memorandum Report for Mercury-Atlas No. 5."

[53] Memo, Roberts to Flight Dir., "Report on Test 1810 (MA–5)," Dec. 5, 1961; memo, Schler to Flight Dir., "Report on Test 1810 (MA–5)," Dec. 4, 1961.

[54] "Postlaunch Memorandum Report for Mercury-Atlas No. 5." Communications with the tracking stations were very good during countdown, and there was little interference. Curiously, however, there was a brief period of interference from Radio Moscow just before liftoff. "Debriefing—Test 1810," anon., Nov. 29, 1961.

[55] Roberts memo.

[56] Memo, Christopher C. Kraft, Jr., "Flight Director's Report on Test 1810 (MA–5)," Nov. 30, 1961; "Postlaunch Memorandum Report for Mercury-Atlas No. 5"; "Debriefing—Test 1810." At his press conference in Washington, President Kennedy got a round of laughter when he said, "This chimpanzee who is flying in space took off at 10:08. He reports that everything is perfect and working well." Baltimore *Sun,* Nov. 30, 1961.

[57] *Ibid.;* NASA News Release, "MA–5 News Conference," Nov. 29, 1961. Williams, in interview Aug. 23, 1965, recalled that communications with California had been disrupted momentarily by a tractor somewhere in Arizona that plowed up a telephone cable.

[58] Stingely and Mosely, "MA–5 Operations," 41–50; "Postlaunch Memorandum Report for Mercury-Atlas No. 5." On the continuous-avoidance, discrete-avoidance problem, Enos received his first shock of the first sessions about 15 minutes from launch and the second at the 201-minute point (after he had been weightless for 3 hours). He then pulled the lever correctly for the last 3 presentations before the psychomotor device turned off 207 minutes after launch.

During the first orbit, in the range of the Zanzibar tracking site, Mercury surgeon White noted that Enos' ventricular contractions had become more rapid. This White believed to be normal for the postacceleration period. The chimpanzee's respiration rate had risen with the onset of flight and the increase in his activity. His respiration rate was 21 and his

pulse 122 during this phase, as compared with preflight rates of 14 and 94.

[59] "Debriefing—Test 1810"; memo, Donald D. Arabian to Flight Dir., "Report on Test 1810 (MA–5)," Dec. 6, 1961; Kraft memo.

[60] *Ibid.;* "Postlaunch Memorandum Report for Mercury-Atlas No. 5."

[61] *Ibid.;* Schler memo.

[62] Kraft memo; Arabian memo; "MA–5 News Conference." The spacecraft used 14.5 pounds of control fuel from retrofire to fuel jettison. Thirty pounds of fuel were dumped when the main parachute deployed.

[63] Kraft memo; "Postlaunch Memorandum Report for Mercury-Atlas No. 5"; "Unofficial Record of Events—MA–5, November 28 [sic], 1961," anon. On Nov. 2, 1961, Low remarked to Purser that MA–5 should be announced as a one-orbit mission that might be allowed to go three orbits. (Purser, log for Gilruth, Nov. 7, 1961.) MA–5's total recovery force, for the support of aborts, primary, and contingency landing areas consisted of 17 ships and 13 airplanes.

[64] "Postlaunch Memorandum Report for Mercury-Atlas No. 5." The drogue and main parachutes were not recovered, but the Earth-sky camera confirmed that they had functioned without damage. The drogue deployed at 21,000 feet and the main chute at 10,000.

[65] "MA–5 News Conference."

[66] Washington *Evening Star,* Dec. 1, 1961; *New York Times,* Dec. 1, 1961; *Chicago Tribune,* Dec. 1, 1961; *Results of the Mercury Chimpanzee Flights,* 38, 54. A little less than a year later, on Nov. 4, 1962, Enos died of dysentery caused by shigellosis, which resists antibiotics. He had been under night-and-day observation for two months before his death. Pathologists at Holloman reported that they found no symptom that could be attributed or related to his space flight a year before.

[67] *New York Times,* Dec. 1, 1961; Kolcum, "Chimp Shot Raises Hope that U.S. Can Orbit Man Before Year's End"; Washington *Evening Star,* Dec. 6, 1961. The fact that Christmas leaves of absence for thousands of naval personnel in the recovery forces might have to be canceled without assurance that the flight schedule would be kept also entered into the decision to postpone MA–6, Williams said in interview.

[68] House Committee on Science and Astronautics, 87 Cong., 2 sess. (1962), *Aeronautical and Astronautical Events of 1961,* 71; Baltimore *Sun,* Dec. 7, 1961; Low memo.

## *Chapter XIII*

[1] *Washington Post,* Jan. 4 and Feb. 3, 1962; Walter C. Williams, interview, Houston, Aug. 23, 1965; House Committee on Science and Astronautics, 88 Cong., 1 sess. (1963), *Astronautical and Aeronautical Events of 1962,* 15–16.

[2] Washington *Evening Star,* Feb. 4, 1962; *New York Times,* Feb. 4, 1962; *Washington Post,* Feb. 6 and 19, 1962; Shirley Thomas, *Men of Space* (Philadelphia, 1962), V, 29–30; "MA–6 Advisory," 5 p.m., Feb. 15, 1962.

[3] *Space News Roundup,* MSC, I (Feb. 7, 1962); "Project Mercury Status Report No. 4 for Period Ending Oct. 31, 1959," STG, 41; "Project Mercury Status Report No. 6 for Period Ending April 30, 1960," STG, 37; "Project Mercury Status Report No. 8 for Period Ending Oct. 31, 1960," STG, 41; Project Mercury Status Report No. 10 for Period Ending April 30, 1961," STG, 37; "Project Mercury Status Report No. 11 for Period Ending July 31, 1961," STG, 37; "Project Mercury Status Report No. 12 for Period Ending Oct. 31, 1961," STG, 34. The flight schedule chart in October 1961 showed an MA–6 alternate mission. This meant that if the Enos (MA–5) flight had not succeeded another chimpanzee mission, designated MA–6, would have been flown.

[4] Paul E. Purser, compilation of excerpts from messages regarding spacecraft No. 13; Ms., George F. Killmer et al., "Project Mercury Technical History—Preflight Operations," MSC Florida Operations, Dec. 30, 1963, 107–111.

[5] Memo, Robert B. Voas to Mercury astronauts, "Suggested Activities for Orbital Flights," Sept. 18, 1961.

[6] *Ibid.*

[7] Interview, Jocelyn R. Gill, Houston, Oct. 11, 1965.

[8] NASA, "Summary Minutes: Astronomy Subcommittee of the NASA Space Sciences Steering Committee (Meeting No. 8)," Dec. 5, 1961, and App. I, "Suggested Astronomical Tasks for the Mercury Astronauts," Nov. 3, 1961.

[9] Memo, Voas to Williams, "Astronauts' Preparation for Orbital Flight," Sept. 25, 1961; "Project Mercury Astronaut Preparation for Orbital Flight," NASA Project Mercury working paper No. 206, Oct. 13, 1961.

[10] *Ibid.*

[11] *Ibid.* In the event of slow pitch upthrust, the astronaut was to assume manual

control of pitch. In retrosequence failure, he was to use manual override. If the main electric power supply failed, he was to select a standby source and determine whether reentry was possible at the end of the first orbit or whether earlier entry was necessary.

[12] "Project Mercury Astronaut Preparation and Activities Manual for Mercury-Atlas Mission 6 (MA–6, Spacecraft 13)," NASA Project Mercury working paper No. 215, Dec. 1, 1961.

[13] NASA, "Summary Minutes: Ad Hoc Committee on Astronomical Tasks for the Mercury Astronauts," Jan. 11, 1962.

[14] NASA, "Summary Minutes: Ad Hoc Committee on Astronomical Tasks for the Mercury Astronaut (Meeting No. 2)," Dec. 20, 1961.

[15] "Astronaut Preparation and Activities Manual for MA–6."

[16] "Project Mercury Status Report No. 13 for Period Ending Jan. 31, 1962," STG, 15, 23; "Postlaunch Memorandum Report for Mercury-Atlas No. 6 (MA–6), Part I, Mission Analysis," March 5, 1962; memo, Richard M. Dunham to Voas, "Personnel Survival Equipment Exercise for 2/7/62," Feb. 8, 1962. The life vest was fabricated as a solution for Grissom's swimming problem at the end of the MR–4 mission. The inflated vest had a bulk of less than 20 cubic inches and weighed less than a pound. *Results of the First United States Manned Orbital Space Flight, February 20, 1962* (Washington, 1962), 39. Also John H. Glenn, Jr., "I'll Have to Hit a Keyhole in the Sky," *Life,* LI (Dec. 8, 1961).

[17] "Status Report No. 13," 24; James M. Grimwood, *Project Mercury: A Chronology,* NASA SP–4001 (Washington, 1963), 157; memo, Eugene F. Kranz to Christopher C. Kraft, Jr., "Report on Test 5460 (MA–6)," Feb. 20, 1962. The flotation collar mentioned in the swimmer-training program resulted partly from the loss of Grissom's spacecraft. It was also the product of two years' work, and credit for its design must go to Donald E. Stullken of the Pensacola Naval Air Station. Early in the Mercury program the engineers realized that their hope of adapting a 20-man life raft to keep a spacecraft afloat was not feasible. The "Stullken collar" passed its final test on Jan. 3, 1962. At that time 50 collars had been made at Pensacola and delivered to the recovery forces. In an earlier test, off Wallops Island, one of the collars had kept the MR–2 capsule afloat for 70 hours in waves up to 7 feet high. The collar was made of five-ply life-raft fabric, was attached to the spacecraft by cables around the impact skirt, and was inflated after attachment. Stullken later became an employee of the Manned Spacecraft Center. *Space News Roundup,* MSC, I (Jan. 10, 1962), 23.

[18] "Project Mercury Mission Directive for Mercury-Atlas Mission 6 (MA–6, Spacecraft 13)," NASA Project Mercury working paper No. 216, Dec. 15, 1961; "Project Mercury, Mercury-Atlas No. 6 Recovery Requirements," Dec. 2, 1961. The latter document said that reentry (.05 g) would start about 60 miles west of Florida's Atlantic coast. Recovery forces were told that as a safety measure the ground track was set to continue 1000 miles beyond the third orbit landing area and that the explosive egress hatch had been modified to keep the cover from traveling more than two feet. Several ships had their cranes or davits fitted with a "shepherd's crook," consisting of a 16-foot aluminum pole with a hardened stainless-steel hook at the cable end which was capable of lifting 10,000 pounds. ("Technical Information Summary for Mercury-Atlas Mission 6 (MA–6, Spacecraft 13)," NASA/MSC, Dec. 19, 1961; "Detailed Test Objectives, NASA Mission No. MA–6, Project Mercury, Contract No. AF 04(647)–930," Aerospace Corp., Nov. 10, 1961.) A planning document for the MA–4 mission had indicated that the Atlas hold-down time would be three seconds, to assure that combustion would smooth out; thereafter, beginning with MA–5, the time would be reduced to two seconds. For MA–6 the hold-down time still was listed for three seconds duration.

[19] "NASA Note to Editors," Dec. 5, 1961.

[20] "Public Information Operating Plan, Project Mercury MA–6," NASA, undated; NASA News Release 62–8, "Mercury-Atlas 6 at a Glance," Jan. 21, 1962. For a descriptive impression of the MA–6 mission, see Ralph O. Shankle, *The Twins of Space* (Philadelphia, 1964), 77–100. During that mission, Shankle was a member of the MSC Public Affairs Office. In an interview, John A. "Shorty" Powers on Nov. 12, 1965, said that in his opinion the delays preceding the Glenn flight produced some helpful effects in the way of news reporting. Stories about the "type of hats that Annie [Glenn's wife] was wearing" began to play out. The reporters were forced to become more technically conversant if they were to file stories that would keep their editors happy as well as justify the Florida expense accounts.

[21] Williams interview.

[22] "Postlaunch Memorandum Report for MA–6"; "NASA News Briefing at the Starlite Paladium," Feb. 13, 1962; *Results of the First United States Manned Orbital Space Flight;* NASA News Release 62, "Mercury Recovery Force," undated; *Space News Roundup,* I (Feb. 7, 1962). On the morning of Jan. 27, Glenn's military service boss, Gen. David M. Shoup, the Marine Corps Commandant, joined him for breakfast. The name Glenn chose for his spacecraft, *Friendship 7,* was painted on No. 13 by artist Cecilia Bibby. See DOD Representative for Project Mercury Support Operations, *Final Report to the Secretary of Defense on Department of Defense Support of Project Mercury: For the Period 1 July 1959 through 13 June 1963,* approved by Leighton I. Davis, Maj. Gen., USAF, 11 Sept. 1963, Chart 6, 15. Also see "Man Marked to Do Great Things," *Life,* LII (Feb. 2, 1962).

[23] Washington *Evening Star,* Jan. 31, Feb. 4, 1962; *Washington Post,* Feb. 6, 1962; *National Observer,* Feb. 4, 1962; *New York Times,* Feb. 6, 1962; *Los Angeles Times,* Jan. 31, 1962; *New York Herald Tribune,* Feb. 4, 1962; *Washington Daily News,* Feb. 7, 1962.

[24] "NASA News Briefing at the Starlite Paladium."

[25] "MA–6 Advisory," NASA, 5 p.m., Feb. 15, 1962; "MA–6 Advisory," 5 p.m., Feb. 19, 1962; "Postlaunch Memorandum Report for MA–6."

[26] "MA–6 Advisory," Feb. 19, 1962; Richard Dunham, John J. Van Bockel, and Paul W. Backer, "Continuation of MA–6 Debriefing," March 7, 1962.

[27] "Postlaunch Memorandum Report for MA–6"; "Procedures Log," Mercury Control Center, Feb. 20, 1962; *Space News Roundup,* I (Feb. 21, 1962).

[28] *Ibid.*; Kranz memo; memo, Stanley C. White to Kraft, "Summary Report on Test 5460 (MA–6)," Feb. 22, 1962.

[29] "Procedures Log"; White memo.

[30] On launch day cloud masses continued to hover over the launch area, causing many of the newsmen present to bet "no liftoff today." A little after 7 a.m. one of the Cape weather men, Harlan G. Higgins, noticed that the wind was shifting to drive the clouds away and that the temperature was becoming cooler. He quickly phoned Ernest A. Amman, the weather support man in Mercury Control, and told him that the chances for launch now looked promising.

[31] "Procedures Log"; White memo; "Postlaunch Memorandum Report for MA–6."

[32] *Ibid.*; "Transcript of Public Address Announcements by Col. John Powers Beginning at T Minus 22 Minutes, Describing MA–6 Launch," Feb. 20, 1962. For the story of the people on the beaches, see *New York Times,* Feb. 20, 1962. The impatience of some of the news personnel was understandable. A *New York Times* correspondent reported in mid-February that the often-postponed Glenn flight had already cost the broadcasters $2 million and that each day of delay cost them another $50,000. Newspaper and magazine costs were estimated at about a third of those figures. *New York Times,* Feb. 17, 1962. Also see "Liftoff! for John Glenn and His Family," *Life,* LII (March 2, 1962); "Liftoff and Uplift for the U.S.," *Life,* LII (March 2, 1962); "He Hit That Keyhole in the Sky," *Life,* LII (March 2, 1962); "At School All Systems Are Go," *Life,* LII (March 9, 1962); D. J. Hamblin, "Applause, Tears and Laughter and the Emotions of a Long-Ago Fourth of July," *Life,* LII (March 9, 1962); "Hero's Words to Cherish," *Life,* LII (March 9, 1962); John Glenn, Jr., "If You're Shook Up You Shouldn't Be There," *Life,* LII (March 9, 1962).

[33] White memo; "Postlaunch Memorandum Report for MA–6." The General Electric-Burroughs booster-guidance system performed an interesting operation. Aboard the Atlas were three small black boxes, two of them similar to two-way radios. A radar on the ground automatically tracked signals emanating from these boxes, determining range and position. The operation for the MA–6 mission progressed along the following pattern: A few minutes before launch time Michael Michela, the GE rate console operator, flipped a switch that pointed the rate antennas in the same directions as the precise tracking radar. This was to obtain velocity data. Thomas Waid, the track console operator, pushed a button to place the guidance system in automatic operation. Guidance system signals were aimed on a "cube in space" several hundred feet above the booster. It was simply a matter of waiting until the booster passed through this area, when the signals locked onto a radio transponder and the system began steering the launch vehicle after staging. This condition was maintained until orbital conditions were attained. The system had operated some 8000 hours before MA–6, and some members of the guidance team, consisting of Rodney Borum, John Savarie, Donald Wood, Waid, Robert

Stanton, and Michela, had participated in as many as 121 launches. (News release, "Radio Guidance Functions of Mercury-Atlas 6," Defense Electronics Div., General Electric Co., undated; News release, no title, Defense Electronics Div., General Electric Co., undated.) During the powered phase of the flight, Kraft was notified that signals from a foreign C-band radar transmitter had been intercepted, but the operations team was unable to identify the source. ("Procedures Log.") The guidance equations were developed by C. L. Pitman, Robert Page, and Duncan McPherson of the Space Technology Laboratories. John P. Mayer, comments, Sept. 8, 1965.

[34] "Postlaunch Memorandum Report for MA-6"; "Procedures Log." At sustainer cutoff Glenn was not only aware of weightlessness but felt as though he were tumbling. Shepard and Grissom reported the same sensation. The apogee of Glenn's flight was 162 miles; the perigee, 100 miles.

[35] "Postlaunch Memorandum Report for MA-6"; "Continuation of MA-6 Debriefing." Glenn felt no angular acceleration during turnaround.

[36] *Ibid.*

[37] "Test 5460, Composite Message Summary," Mercury Control Center, Feb. 20, 1962. Over the Kano area on the first pass, Glenn opened his faceplate and ate a xylose (sugar) pill and his tube of applesauce without difficulty. (*Results of the First United States Manned Orbital Space Flight,* 153.) In the Zanzibar area Glenn worked out briefly with his exerciser, and the tracking station noted a temporary increase in his pulse rate to 140.

[38] The engineers later stated that these disagreements were inherent and would crop up whenever major yaw or roll attitudes deviated from zero degrees for an extended period of time. In other words, the gyro "readouts" on the panel, which were reporting an attitude change of about four degrees per minute, were considerably behind Glenn's quickly slewing yaw maneuver. Consequently the best procedure when executing such an operation was to stop the revolving gyroscopes, an action called "caging."

[39] "Postlaunch Memorandum Report for MA-6"; "Test 5460, Composite Message Summary"; "Transcript of Announcements by John Powers"; "Continuation of MA-6 Debriefing." Upon meeting the mayor of Perth later, Glenn remarked facetiously that he had half-expected the mayor to hand him an electric bill. An attempt to observe the airport lights at Woomera had failed because of cloudiness. As for the height of the haze layer, Jocelyn R. Gill of NASA Headquarters said this distance was later measured and found to be about 2½ degrees above the horizon. For other comments on Glenn's observations while in orbit see "National Aeronautics and Space Administration," *Astronomical Journal,* 67, No. 9, Nov. 1962, 655.

[40] "Procedures Log"; "Continuation of MA-6 Debriefing." The particles appeared to be about 1/10 inch in diameter and to be traveling at about the same speed as the spacecraft.

[41] "Postlaunch Memorandum Report for MA-6." On Feb. 26, 1962, postflight inspectors disassembled the thrust chamber systems and found some loose particles upstream of the fuel-metering orifices. These were found to be pieces of the dutch-weave fuel-distribution screens. Fuel consumption during the first orbit was 4.2 pounds from the automatic tanks and .6 pound from the manual tanks. Those figures were nominal; control trouble did not develop until the flight had been in progress for an hour and 29 minutes.

[42] *Ibid.; Space News Roundup,* I (Feb. 21, 1962); William Hines, "Segment 51," Washington *Evening Star,* March 16, 1962; Maxime A. Faget, interview, Houston, April 19, 1962.

[43] Postflight inspectors were unable to explain the secondary oxygen supply drop. For a report on Glenn's observational efforts, see John H. Glenn, Jr., "Summary Results of the First United States Manned Orbital Space Fight," in *Life Sciences and Space Research,* "A Session of the Third International Space Science Symposium," Washington, D.C., April 30–May 9, 1962 (North Holland Publishing Company, Amsterdam, Netherlands, 1962), 173–183.

[44] "Procedures Log."

[45] *Ibid.;* "Postlaunch Memorandum Report for MA-6"; "Test 5460, Composite Message Summary"; *Results of the First United States Manned Orbital Space Flight,* 190; "Continuation of MA-6 Debriefing."

[46] *Ibid.*

[47] "Postlaunch Memorandum Report for MA-6."

[48] "Postlaunch Memorandum Report for MA-6." At the moment of Glenn's splashdown, the Post Office issued a special 4-cent stamp commemorating the MA-6 mission ("Transcript of Announcements by John Powers"). For a popular account of the MA-6 mission, with excellent illustrations, see Robert B. Voas, "John Glenn's Three Orbits in *Friend-*

*ship 7," National Geographic,* reprinted from the June 1962 magazine.

[49] *Ibid.; Astronautics,* VII (May 1962). In a debriefing session a few days after the MA–6 flight, Glenn said he wished he had known of the supposed heatshield and landing bag problem, so that he could have been listening for sound clues. He seemed to be making the point that the pilot, as the thinking part of the man-machine team, should be allowed to participate in decision making. Scott Crossfield, one of the X–15 pilots, expressed this view well in the immediate post-MA–6 period: "Where else would you get a non-linear computer weighing only 160 pounds, having a billion binary decision elements, that can be mass-produced by unskilled labor?" "Continuation of MA–6 Debriefing"; *Aviation Week,* LXXVI (March 5, 1962).

[50] *Astronautical and Aeronautical Events of 1962,* 18. See Senate Committee on Aeronautical and Space Sciences, 87 Cong., 2 sess. (1962), *Orbital Flight of John H. Glenn, Jr.,* for testimony of astronauts and NASA officials, Feb. 28, 1962.

[51] "Free World Media Treatment of First U.S. Orbital Flight," a file of reports assembled at NASA Hq., March 5, 1962.

[52] *Aviation Week,* LXXVI (Feb. 26, 1962). Robert R. Gilruth also was the cover subject for *Missiles and Rockets,* X (March 19, 1962). The same issue of the magazine said in an editorial: "It is always a pleasure to sing about an unsung hero. . . . While Astronaut John Glenn was swinging around the earth in *Friendship 7* . . . Robert Gilruth had his feet planted firmly on the ground in Mercury Control." Gilruth had just been awarded the Robert H. Goddard Memorial Trophy on March 16, 1962, by the National Rocket Club.

[53] *Astronautical and Aeronautical Events of 1962,* 22, 27; *Friendship 7* tour files, MSC Hist. Archives; Grimwood, *Mercury Chronology,* 184. The text of Glenn's address to the joint session of Congress may be found in the *Washington Post* for Feb. 27, 1962.

[54] Reports and photographs concerning the "Fourth Orbit of *Friendship 7*" are filed in the MSC Hist. Archives.

[55] *Washington Post,* Jan. 10, 1962; Washington *Evening Star,* Jan. 6, 1962; David S. Akens, Paul K. Freiwirth, and Helen T. Wells, *History of the George C. Marshall Space Flight Center* (Huntsville, Ala., 1960–1962), I, 21; "Saturn Illustrated Chronology: April 1957–June 1964," NASA/MSFC, Aug. 10, 1964, 52–53; Newport News *Daily Press,* Jan. 4, 1962.

[56] See Chap. X. House Committee on Science and Astronautics, 87 Cong., 2 sess. (1962), *1963 NASA Authorization, Hearings,* 1, 2.

[57] *Ibid.,* 3–33; Senate Subcommittee of the Committee on Appropriations, 87 Cong., 2 sess. (1962), *Independent Offices Appropriations, 1963, Hearings,* II, 1503; Washington *Evening Star,* Jan. 7, 1962.

[58] MSC announcement No. 9, Ref. 2–2, "Establishment of the Mercury Project Office," Jan. 15, 1962.

[59] MSC announcement No. 12, Ref. 2–2, "Personnel Assignments for Mercury and Gemini Program Offices," Jan. 31, 1962; Maggie Taylor, Apollo Spacecraft Program Office, MSC, interview, Houston, Jan. 12, 1965; Grimwood, *Mercury Chronology,* 220.

[60] Memo, Dir. of Personnel, MSC, to Philip H. Whitbeck, "Status Report for the Personnel Office," Jan. 26, 1962. At the time of the personnel survey about 400 to 500 could have been termed "old guard." The remainder, being essentialy "new hires," did not really care whether they settled in Hampton or Houston. The 84 who chose not to go were mainly of the "old guard."

[61] MSC announcement No. 21, Ref. 2–1, "Relocation of Manned Spacecraft Center Headquarters," Feb. 26, 1962. In reality the Mercury Project Office moved into the Farnsworth-Chambers Building in Houston on April 16, 1962, a move that preceded the MA–7 flight by a little over a month.

[62] *Astronautical and Aeronautical Events of 1962,* 36; Donald K. Slayton, interview, Houston, Dec. 16, 1964; letter, William Douglas to L. S. S., Jr., Aug. 17, 1965.

[63] During the December 1964 interview Slayton demurred at naming the civilian panel, but newsmen had been less reticent. See *Washington Post,* March 16, 1962; *New York Times,* March 16, 1962. For other material on the Slayton case, see Mae M. Link, *Space Medicine in Project Mercury,* NASA SP–4003 (Washington, 1965). Slayton was not examined personally by Paul Dudley White until June 15, 1962. At that time speculation was revived about Slayton's possible selection for a space flight. Washington *Evening Star,* June 15, 1962.

[64] Washington *Evening Star,* March 21, 1962; Slayton interview; Paul E. Purser, interview, Houston, Jan. 4, 1965.

## FOOTNOTES

[65] Slayton, interview, Houston, Jan. 14, 1965; "Postlaunch Memorandum Report for Mercury-Atlas No. 7 (MA-7), Part I, Mission Analysis," NASA/MSC, June 15, 1962. After MA-7 each backup pilot became the flight astronaut of the succeeding mission in Project Mercury. Also see Loudon Wainwright, "Comes a Quiet Man to Ride Aurora," *Life*, LII (May 18, 1962).

[66] "Technical Information Summary for Mercury-Atlas Mission 7 (MA-7, Spacecraft 18)," MSC, undated.

[67] Gill interview; NASA, "Summary Minutes: Ad Hoc Committee on Scientific Tasks and Training for Man-in-Space (Meeting Nos. 1, 2, 3)," March 16, 26, and April 18, 1962.

[68] NASA News Release 62-113, "MA-7 Press Kit," May 13, 1962.

[69] "Project Mercury Mission Directive for Mercury-Atlas Mission 7 (MA-7, Spacecraft 18)," NASA Project Mercury working paper No. 222, April 9, 1962; "Postlaunch Memorandum Report for MA-7"; *Results of the Second United States Manned Orbital Space Flight, May 24, 1962*, NASA SP-6 (Washington, 1962), 11-13. In the order listed in the text, the experiments were proposed by the Langley Research Center, Lewis Research Center, Massachusetts Institute of Technology Instrumentation Laboratory, the Weather Bureau, and Goddard Space Flight Center.

[70] *Ibid.* Airglow is an emission of light resulting from chemical reactions in the upper atmosphere. Various reactions produce light of different colors. In many cases, molecules of atmospheric gas are split by ultraviolet rays of sunshine. Then, when darkness comes, the gas molecules recombine, emitting light. The illumination of the sky at night usually comes from airglow instead of starlight. *New York Times*, June 3, 1962. Lawrence Dunkelman of Goddard provided Carpenter with the airglow device to make observations. Jocelyn Gill said this was the filter that had been planned for MA-6, but time did not permit Glenn to use it.

[71] *Ibid.*; "Project Mercury Quarterly Status Report No. 14 for Period Ending April 30, 1962," NASA/MSC, May 25, 1962. John Mayer of MSC commented in September 1965, "that photos of the Russian spacecraft indicated that they had an almost identical earth-path indicator." Mayer went on to say that the indicator "was deleted from Mercury flights because it was of little use in the missions."

[72] "Project Mercury Mission Directive for Mercury-Atlas Mission 7"; message, G. Merritt Preston to Gilruth, May 21, 1962; "Weekly Activity Report to the Office of the Director for Manned Space Flight," MSC, May 5, 1962.

[73] "Project Mercury Quarterly Status Report No. 14"; "Weekly Activity Report," MSC/Mercury Project Office, March 17, 1962; "Postlaunch Memorandum Report for MA-7."

[74] Memo, Kraft to Williams et al., "MA-7 Test Flight Reports," June 12, 1962; "Project Mercury Mission Directive for Mercury-Atlas Mission 7"; *Final Report to the Secretary of Defense on Support of Project Mercury*, Chart 6, 15. The Indian Ocean picket ship *Coastal Sentry* (call name "Coastal Sentry Quebec") was stationed at the entrance to the Mozambique Channel off the southeastern coast of Africa for MA-7. "MA-7 Press Kit."

[75] "Project Mercury Quarterly Status Report No. 14." The decision to add a barostat in the recovery arming circuit was a primary reason for delaying the MA-7 launch. After a review meeting on May 16, the engineers had decided that this action was necessary. Late that night the newsmen already at the Cape were advised.

[76] Kraft memo; memo, Harold I. Johnson et al., to those concerned, "MA-7 Remote Site Operations Debriefing," June 1, 1962; "Postlaunch Memorandum Report for MA-7."

[77] Johnson memo.

[78] "Postlaunch Memorandum Report for MA-7." The *New York Times* for May 26, 1962, reported the estimated number of television viewers. Cecilia Bibby was again selected as the artist to paint the name chosen by the astronaut. *New York Times*, May 28, 1962.

[79] Kraft memo; "Postlaunch Memorandum Report for MA-7."

[80] Orbital insertion of *Aurora 7* was almost ideal, the flight path angle and velocity being only .004 degree and 2 feet per second low, respectively. This provided an orbital trajectory of 89.96 miles (perigee) and 144.4 miles (apogee). There was only one anomaly during the powered phase of the flight. The primary auxiliary cutoff signal for the sustainer engine was transmitted by the General Electric-Burroughs guidance system simultaneously with sustainer engine cutoff. The backup auxiliary sustainer cutoff signal had preceded this transmission by .44 second. But the abort enabling switch in the Control Center was in the normal position; since both signals did not lock, an improper signal was prevented. If the launch

vehicle had accepted the erroneous signal, a velocity decrement of about 110 feet per second might have resulted, causing marginal conditions in the go-for-mission decision. ("Postlaunch Memorandum Report for MA–7"; "Project Mercury Quarterly Status Report No. 15 for Period Ending July 31, 1962," NASA/MSC.) Carpenter said the sensations of weightlessness were similar to those of skin-diving.

[81] Kraft memo; "Postlaunch Memorandum Report for MA–7"; *Results of the Second United States Manned Orbital Space Flight,* 78–79. Postflight inspection convinced several engineers that the malfunction of the horizon scanner circuit was a random component failure. Plans were made to try to recover the antenna canister on the next flight for postflight analysis of the scanner unit located in that component. ("Project Mercury Quarterly Status Report No. 15.") Concerning the undesirable suit temperatures, Frank H. Samonski, Jr., capsule environmental monitor, believed a partial freezing in the suit circuit caused an obstruction in the heat exchanger. Carpenter was comfortable once again by the end of the first orbit; he was hot again during the second; and he finally got the suit temperature down to a comfortable level on the third. Suit inlet temperatures ranged between 62 degrees to about 86 degrees during the flight. In all, Carpenter made 13 attempts to adjust the setting to a comfortable range.

[82] *Ibid.;* Washington *Sunday Star,* March 27, 1962. Carpenter later said that the periscope was not worth the weight and space it occupied in the spacecraft. This certainly would be true, he felt, when longer Mercury missions required more oxygen, water, and control fuel. On other aspects of the flight, Carpenter reported that he even saw a dirt road so clearly that he had the impression that if a vehicle had come along he could have seen it, too. In general, he found the daylight view from orbit similar to a view from a high-flying aircraft. He said that navigation at night might be accomplished by using a known star on the horizon.

[83] "Postlaunch Memorandum Report for MA–7."

[84] *Ibid.*

[85] *Ibid.;* Kraft memo.

[86] *Ibid.;* Newport News *Times-Herald,* June 7, 1962; Johnson memo. Carpenter also consumed a xylose tablet without difficulty. At about midway of the second orbit, the flight controller recommended that the pilot drink water freely to compensate for sweating. Carpenter drank about 1213 cc of water—60 percent while in flight and the remainder while on the life raft awaiting recovery. During the postflight debriefings, Carpenter suggested that henceforth food bags should be transparent and that something should be done about the chocolate items, which had melted in the fluctuating warmth of the cabin.

[87] "Postlaunch Memorandum Report for MA–7." Shortly after retrofire the balloon disappeared, and about seven minutes later, Carpenter lost sight of the tether.

[88] *Ibid.;* Johnson memo; Grimwood, *Mercury Chronology,* 164–165.

[89] "Postlaunch Memorandum Report for MA–7." Also see Winifred Sawtell Cameron, Lt. Col. John H. Glenn, Lt. Cdr. M. Scott Carpenter, and John A. O'Keefe, "Effect of Refraction on the Setting Sun as Seen from Space in Theory and Observation," in the *Astronomical Journal,* 68, No. 5, June 1962, 348–351.

[90] *Results of the Second United States Manned Orbital Space Flight,* 92, 102–103; *New York Times,* June 3, 1962. Later, Lawrence Dunkelman at Goddard, using Carpenter's "Voasmeter" readings, judged the airglow layer to be about two degrees in width. Also, after the Carpenter mission, the Naval Research Laboratory began a study of the night airglow from pictures taken during rocket flights. For the findings of this study see M. J. Koomen, Irene S. Gulledge, D. M. Packer, and R. Tousey, "Night Airglow Observations from Orbiting Spacecraft Compared with Measurements from Rockets," *Science,* Vol. 140, No. 3571, June 7, 1963, 1087–1089.

[91] "Postlaunch Memorandum Report for MA–7." Out of 19 exposed frames, Carpenter was able to get two pictures of the "fireflies." Evidence appeared in other photographs, but these pictures were not in focus.

[92] Kraft memo.

[93] *Ibid.;* Johnson memo; "Postlaunch Memorandum Report for MA–7." Joe Dodson, in an interview, reported that about 18½ pounds of fuel were depleted during the first 10 minutes of reentry. Newport News *Daily Press,* June 6, 1962. When Carpenter switched on the ASCS, the spacecraft had a tendency to pitch down. Fuel conservation during the third orbit had prevented an adequate checkout of the ASCS before retrofire.

[94] Kraft memo; Johnson memo. The interior smoke resulted not from the retrorockets

themselves, but from two fuses that had blown because of the retros' kick.

[95] Memo, Carl R. Huss, et al., to Chief, Flight Operations Div., "Postflight Analysis of MA–7 Trajectory Data to Determine Cause of the Erroneous Landing Point," June 13, 1962; *New York Times,* June 6, 1962. Almost immediately the tracking crews across the nation, beginning in California, confirmed that there would be about a 250-mile overshoot.

[96] Johnson memo.

[97] *Ibid.;* "Postlaunch Memorandum Report for MA–7."

[98] Johnson memo. After the MA–6 flight the Life Systems Division had conducted a manned test to investigate the reentry heating that had occurred. Results showed that closing the helmet visor before reentry and letting the suit circuit operate separately provided a more comfortable environment. At the same time it was decided to lengthen the suit inlet hose. ("Activity Report, Life Systems Division," MSC, April 30, 1962.) After .05 g had been passed on Carpenter's flight, the liquid in the capillary tube began to drain. Thus the results tended to confirm capillary action theory. The ability to maintain a stable fluid position during angular acceleration imposed by the reaction control system indicated that this method of ullage control was valid. The results obtained during MA–7 could be extrapolated for propellants in accordance with laws governing each, namely, surface tension, fluid temperature, and known capillary tube diameter. "Postlaunch Memorandum Report for MA–7."

[99] "Postlaunch Memorandum Report for MA–7."

[100] "Postlaunch Memorandum Report for MA–7"; Kraft memo. During the MA–6 ionization period an erroneous command signal had been received. Engineers believed that this was caused by a mixing of radio-frequency signals, which generated sufficient strength to energize one relay in the command system. This anomaly had been corrected by exchanging the low-frequency telemetry components for others operating on a higher frequency. ("Weekly Activities Report," March 17, 1962; "Highlights, Activities Report, MSC," April 30, 1962.) Ionization during MA–7 was 40 seconds late, furnishing another clue to the overshoot. The behavior of the drogue and main chutes remained unexplained. Tests in early May 1962, at El Centro, Calif., using the exact MA–7 weight had all been successful. Memo, Aleck C. Bond to Faget, "Weekly Activity Report," May 4, 1962.

[101] "Postlaunch Memorandum Report for MA–7"; Kraft memo.

[102] *Ibid.;* Washington *Sunday Star,* May 27, 1962; "Project Mercury Quarterly Status Report No. 15."

[103] Johnson memo; *New York Times,* May 26, 1962. Carpenter later learned that the Apache pilot's film was confiscated when he returned to Puerto Rico. The pilot had violated the airway zones.

[104] "Postlaunch Memorandum Report for MA–7"; Johnson memo; *New York Times,* May 26, 1962; Washington *Sunday Star,* May 27, 1962. Sergeant Ray McClure, a veteran of 137 jumps, had received the Air Medal for his part in the first successful recovery of a Discoverer capsule in the Pacific north of Hawaii.

[105] Johnson memo.

[106] Kraft memo. A rather complete discussion of the Carpenter recovery matter is contained in Senate Committee on Aeronautical and Space Sciences, 87 Cong., 2 sess. (1962), *NASA Authorization for Fiscal Year 1963: Hearings,* 495–504. Senator Spessard L. Holland (D. Fla.) and D. Brainerd Holmes of NASA, the latter having been present in the Mercury Control Center during the complete recovery, were the principals in this discussion. Holmes stated that he was with R/A John L. Chew and that it did not seem to make a particle of difference to the admiral which service recovered the astronaut. The NASA official interpreted that Chew based his decision on past experiences; Holmes added that he could detect no feeling of interservice rivalry.

[107] "Postlaunch Memorandum Report for MA–7"; Johnson memo; Washington *Evening Star,* May 26, 1962; *Astronautical and Aeronautical Events of 1962,* 86. See also Rene Carpenter, "Scott Carpenter and His Son and His Wife Living Through the Time That Grew Too Long," *Life,* LII (June 1, 1962); and M. Scott Carpenter, "I Got Let in on the Great Secret," *Life,* LII (June 8, 1962).

[108] "Postlaunch Memorandum Report for MA–7."

[109] *New York Times,* May 28, 1962; *Astronautical and Aeronautical Events of 1962,* 89; *Washington Post,* May 30, 1962; Washington *Evening Star,* May 31, 1962. Carpenter, his family, and the Williams family paid a visit to the White House on June 5, 1962. *Washington Post,* June 5, 1962.

[110] Kraft memo; Johnson memo; "Postlaunch Memorandum Report for MA–7"; John

W. Finney, "Astronaut Says His Errors Will Benefit Space Project," *New York Times*, May 28, 1962. Carpenter's contentions were borne out by the changes that were effected. For one thing a drive was made to have a flight plan specifying fewer activities ready well before the next flight. Also, a switch was integrated in the spacecraft by which the pilot could switch off and switch on the high thrusters. If the pilot forgot to reactivate the thrusters, an automatic override ensured their availability just before retrofire. "Project Mercury Quarterly Status Report No. 15"; *Results of the Second United States Manned Orbital Space Flight*, 6.

[iii] Newport News *Daily Press*, June 6 and 8, 1962; *New York Times*, June 14, 1962; *Washington Post*, June 28, 1962; Washington *Evening Star*, June 14, 1962. On the subject of pilot selection, the month of June was another milestone in the manned space flight program. On June 1 the deadline closed for applications by astronaut candidates for the second increment to be added to the Mercury seven for the Gemini and Apollo missions. *Astronautical and Aeronautical Events of 1962*, 93.

## *Chapter XIV*

[1] Memo, Richard E. Day, to Management Analysis Office, "Monthly Activity Report, Flight Crew Operations Division," July 30, 1962; memo, Warren J. North [to Management Analysis Division], "Activity Report, Flight Crew Operations Division," Aug. 28, 1962; "Flight Plan for MA-8/16," NASA/MSC, Aug. 7, 1962; "Postlaunch Memorandum Report for Mercury-Atlas No. 8 (MA-8)," NASA/MSC, Oct. 23, 1962, Part I, "Mercury Scientific Experiment Panel: Abstract of the Proceedings at the MA-8 Meeting," MSC, July 19, 1962.

[2] House Committee on Science and Astronautics, 88 Cong., 1 sess. (1963), *Astronautical and Aeronautical Events of 1962* (Washington, 1963), 148, 153; "A Space Gap? And How!" *Washington Daily News*, Aug. 13, 1962; "Orbiting Reds Nearing Each Other, Western Ground Observers Report," *Washington Post*, Aug. 14, 1962; "Soviet Prestige in Space," Washington *Evening Star*, Aug. 19, 1962; Seymour Topping, "Russian Astronauts Only 3 Miles Apart on Closest Paths," *New York Times*, Aug. 22, 1962.

[3] "Minutes of the Senior Staff Meeting," MSC, Aug. 24, 1962; memo, North [to Management Analysis Division], "Activity Report, Flight Crew Operations Division," Sept. 23, 1962. A rather complete series of proposals for the maneuvering Mercury spacecraft, including pictures of possible configurations, is contained in "Mercury Maneuvering Proposal," NASA/MSC, Aug. 29, 1962.

[4] Kenneth S. Kleinknecht, interview, Houston, May 3, 1965; "Mercury Seven-Orbit Mission Capability," memorandum report, Mercury Project Office, March 5, 1962.

[5] "Mercury Seven-Orbit Mission Capability."

[6] "MA-8 Mission Rules—Preliminary," Aug. 3, 1962; Revision A, Aug. 20, 1962; Revision B, Sept. 24, 1962; "MA-8 Data Acquisition Plan," Aug. 21, 1962; "MA-8 Technical Information Summary" [Aug. 20, 1962]; "Flight Plan for MA-8/16, Revision A," Sept. 10, 1962; "Mission Directive for Mercury-Atlas Mission No. 8 (MA-8—Spacecraft 16)," NASA Project Mercury working paper No. 228, Aug. 31, 1962; "Calculated Preflight Trajectory Data for Mercury-Atlas Mission 8 (MA-8) (Spacecraft No. 16—Atlas 113-D)," NASA Project Mercury working paper No. 229, Sept. 7, 1962; "MA-8 Recovery Requirements," Aug. 15, 1962; "MA-8 Recovery Procedures," Aug. 30, 1962.

[7] Ms., George F. Killmer, Jr., et al., "Mercury Technical History—Preflight Operations," MSC Florida Operations, Dec. 30, 1963, Chart 126; "Weekly Activities Report," Mercury Project Office, April 20, 1962; "Weekly Activities Report," Mercury Project Office, April 13, 1962; "Project Mercury Quarterly Status Report No. 14 for the Period Ending April 30, 1962," NASA/MSC, May 25, 1962; "Weekly Activity Report to the Office of the Director for Manned Space Flight," MSC, May 5, 1962; memo, G. Merritt Preston to Dir., MSC, "Monthly Activities Report No. 6," April 26, 1962.

[8] Memo, James P. Henry to Asst. Dir. for Research and Development, MSC, "Weekly Activity Report for the Life Systems Division," April 20, 1962; "Monthly Activities Report," Life Systems Div., April 30, 1962; memo, Richard S. Johnston to Asst. Dir. for Research and Development, MSC, "Weekly Activities Report," June 15, 1962; memo, Edward L. Hays to Asst. Dir. for Research and Development, "Weekly Activity Report," May 18, 1962; "Activities Report to the Office of the Director for Manned Space Flight," MSC, May 19, 1962.

[9] "Activity Report to the Office of the Di-

rector for Manned Space Flight," MSC, May 12, 1962; "Activity Report to Director for Manned Space Flight," MSC, June 2, 1962.

[10] Robert T. Everline, interview, Houston, April 15, 1965; "Minutes of the Senior Staff Meeting," MSC, Aug. 3, 1962.

[11] "Weekly Activities Report for the Director of Manned Space Flight," MSC, Aug. 11, 1962; "Weekly Activities Report for the Director of Manned Space Flight," MSC, Sept. 1, 1962; Kenneth J. Vogel, interview, Houston, May 6, 1965; Fred T. Pearce, interview, Houston, Feb. 12, 1964.

[12] "Postlaunch Memorandum Report for Mercury-Atlas No. 7 (MA–7)," NASA/MSC, June 15, 1962; "Postlaunch Memorandum Report for Mercury-Atlas No. 8 (MA–8)."

[13] *Ibid.;* "Project Mercury Quarterly Status Report No. 15 for Period Ending July 31, 1962," NASA/MSC.

[14] "Postlaunch Memorandum Report for MA–8," Part I.

[15] "Minutes of the Senior Staff Meeting," MSC, July 13, 20, Aug. 3, 1962.

[16] *Astronautical and Aeronautical Events of 1962,* 158; "Project Mercury Quarterly Status Report No. 16 for Period Ending October 31, 1962," NASA/MSC; "Minutes of the Senior Staff Meeting," MSC, Aug. 31, 1962.

[17] "Activity Report," MSC Preflight Operations Div., July 27, 1962; James M. Grimwood, *Project Mercury: A Chronology,* NASA SP–4001 (Washington, 1963), 214; "Minutes of the Senior Staff Meeting," MSC, Aug. 17, 1962; "Project Mercury Minutes of Meeting of Mercury Atlas Launch Operations Committee," NASA/MSC, Sept. 6, 1962; "Minutes of the Senior Staff Meeting," MSC, Sept. 28, 1962. J. F. Wambolt on July 26, 1962, prepared a "Missile 113–D History" that provides excellent details on the steps taken to man-rate a missile into a Mercury launch vehicle.

[18] Letter, Maj. Gen. Leighton I. Davis, Hq., Air Force Missile Test Center, to Secretary of Defense Robert S. McNamara, "Status of DOD Support of Project Mercury for July 1962," with enclosure, Aug. 13, 1962; memo, North to Management Analysis Div., "Weekly Activity Report, Flight Crew Operations Division," July 2, 1962.

[19] DOD Representative for Project Mercury Support Operations, *Final Report to the Secretary of Defense on Department of Defense Support of Project Mercury: For the Period 1 July 1959 through 13 June 1963,* approved by Leighton I. Davis, Maj. Gen., USAF, 11 Sept. 1963, 15, 28; "Status Report No. 15"; "Status Report No. 16"; memo, Christopher C. Kraft, Jr. [to Management Analysis Div.], "Activities Report, Flight Operations Division," Aug. 27, 1962; "Minutes of the Senior Staff Meeting," July 27 and Aug. 10, 1962; Department of Defense press kit for MA–8.

[20] *Final Report to the Secretary of Defense,* 28; letter, Davis to McNamara, "Postlaunch Memorandum Report for MA–8."

[21] Text, "Address by President John F. Kennedy," Rice University Stadium, Sept. 12, 1962.

[22] "Astronaut's Flight Report," in "Postlaunch Memorandum Report for MA–8," Part I, 7–49.

[23] Robert Young, "Squalls Give Schirra Orbit 50–50 Chance," *Chicago Tribune,* Oct. 2, 1962; "Schirra Ready for Countdown," *Washington Post,* Oct. 3, 1962; NASA News Release, "MA–8 Advisory," 5 p.m., Oct. 2, 1962.

[24] "Postlaunch Memorandum Report for MA–8," Part I; Alvin B. Webb, United Press International, "Hangar S Pool Copy," Oct. 3, 1962. Also see "High Dreams for a Man and His Son," *Life,* LII (June 8, 1962).

[25] The description and all quotations in the following account of the MA–8 flight are taken directly from the extensive "Postlaunch Memorandum Report for Mercury-Atlas No. 8 (MA–8): Part I, Mission Analysis; Part II, Data; Part III, Air-Ground Voice and Debriefing." MSC, Oct. 23, 1962.

[26] *Results of the Third United States Manned Orbital Space Flight October 3, 1962,* NASA SP–12 (Washington, 1962), 49. The contents of the ditty bag included a camera, two film magazines, an exposure meter, a camera strap, a photometer, a dosimeter, food containers, and an emergency container for motion sickness. See also Grimwood, *Mercury Chronology,* 172.

[27] "Flight Operations Debriefing of MA–8 Mission [aboard the carrier *Kearsarge*]," MSC, transcribed Oct. 23, 1962. Like Glenn and Carpenter before him, Schirra said he definitely sensed deceleration at BECO. On the other hand, he did not sense the acceleration tailoff that they had reported when the sustainer engine died. Max-q proved to be considerably noisier than Schirra had been led to expect. During the launch phase he heard many audible clues telling him what was taking place. These he described onomatopoeically, speaking of the jettisoning tower as "a rocket zapping off," of the clamp ring's release of the

spacecraft with a "pung" sound, and of the posigrades' separating spacecraft from booster with a noise that sounded like "khuee."

[28] Fuel usage for the turnaround was only about a tenth of the amount required in previous flights.

[29] For the public dialogue, see "Postlaunch Memorandum Report for MA–8," Part III, Air-Ground Voice and Debriefing, 2–129, 2–130.

[30] Cf. "Postlaunch Memorandum Report for Mercury-Atlas No. 8 (MA–8)," Part I, 7–1–49; Part III, pp. 3–1–18; and "Flight Operations Debriefing of MA–8 Mission," 1–38. See also *Results of the Third United States Manned Orbital Flight*; and messages filed by news pool aboard the *Kearsarge*, Oct. 3, 1962. The fact that Schirra had landed so close to the carrier prompted the engineer who had calculated the retrofiring so precisely to quip that "the carrier must have been 4.5 miles off course."

[31] Notes, John Barbour, Associated Press, "Mercury Control Center Postflight News Conference," Oct. 3, 1962.

[32] "Schirra Flying to Houston after 3-Hour Honolulu Visit," Washington *Evening Star*, Oct. 7, 1962; "MA–8 Press Conference, Houston, Texas," transcript, Oct. 7, 1962; *New York Herald Tribune*, Oct. 9, 1962. Also see John Dille, "At the End of a Great Flight, Big Bull's-Eye," *Life*, LIII (Oct. 12, 1962); and "Bull's Eye from a Front-Row Seat," *Life*, LIII (Oct. 26, 1962); and the special issue of *Newsweek*, LX (Oct. 8, 1962), "The Space Age," passim.

[33] James M. Grimwood, who came to work for STG/MSC in August 1962, remembers clearly this contrast in attitudes.

[34] Letter, A. H. Smith, McDonnell Aircraft Corp., to NASA Procurement and Supply Office, "Mercury Capsule Contract NAS 5–59, Contract Change Proposal No. 340, Eighteen-Orbit Mark I Spacecraft," Sept. 29, 1961; "Project Development Plan for Research Development Utilizing the Mark II Manned Spacecraft," MSC, Langley Air Force Base, Va., Dec. 8, 1961; "Operational Plan for 18-Orbit Manned Mission," STG, Oct. 5, 1961.

[35] On "newspeak," cf. "Project Mercury Status Report No. 12 for Period Ending Jan. 31, 1962," STG. On reorganization, see Grimwood, *Mercury Chronology*, 152, 219; and *NASA Sixth Semiannual Report to Congress, July 1 through December 21, 1961* (Washington, 1962), 137, 139. On the state of the art of physiological research before MA–9, see J. C. Simons and W. N. Kama, "A Review of the Effects of Weightlessness on Selected Human Motions and Sensations," AMRL memorandum P–36, Wright-Patterson Air Force Base, Ohio, May 1963; James P. Henry, "Physiological and Performance Aspects of Weightlessness," MSC fact sheet No. 73, 1962.

[36] For 1961 feasibility studies, see "Mercury Spacecraft Advanced Versions," AD 61, 224B, control No. C–57978, McDonnell Aircraft Corp., 1961; NASA briefing charts, undated, A–28358, Ames Research Center, 1–31. For MODM evolution, see Robert T. Everline, Edward B. Hamblett, Jr., and William R. Humphrey, "Preliminary Mercury 18-Orbit Spacecraft Information Document," MSC memorandum report, Jan. 11, 1962; Lewis R. Fisher, "Mercury 18-Orbit Information Document (Minimum Weight Spacecraft)," MSC memo report, Jan. 19, 1962. For the basic specification for MODM, see Everline et al., "Manned One-Day Mission Mercury Spacecraft Specification Document," NASA Project Mercury working paper No. 223, April 23, 1962. On concurrent progress with Gemini, see *Astronautical and Aeronautical Events of 1962*, 43, 199.

[37] "Project Mercury Quarterly Status Report No. 16," 1; "Minutes of the Senior Staff Meeting," MSC, Nov. 9, 1962. MSC learned of NASA's formal approval of a 22-orbit flight five weeks later. "Minutes of the Senior Staff Meeting," MSC, Dec. 14, 1962. Orbit 21 would duplicate orbit 6, but MSC decided on 22 orbits to optimize the recovery location near Midway Island again and the margins for error in spacecraft systems and supplies.

[38] Letter, J. Y. Brown, McDonnell Aircraft Corp., to NASA/MSC Mercury Procurement Office, with enclosure, "Financial Status Summary, Mercury One-Day Mission Contract NAS 5–59," Oct. 11, 1962. The major mission-planning meeting for MA–9 was held at Patrick Air Force Base on Dec. 3 and 4, 1962. See Davis, "Minutes of Pre-Operational Conference for Project Mercury One-Day Mission (MA–9)," Dec. 18, 1962.

[39] Mss. for Project Mercury Tech. Hist. Program, Robert B. Merrifield, "Organization," July 1963, Part I, B, 14; and Marvin F. Matthews, "Patents," Oct. 22, 1963, Part I, H. See also Grimwood, *Mercury Chronology*, 178. Two of the "Mercury inventors" were no longer with MSC: Alan B. Kehlet had left government service to work on Apollo for North American Aviation, and Willard S. Blanchard had remained at Langley, saying

"It was hot enough for me right here." Kehlet, interview, Downey, Calif., Aug. 27, 1964; Blanchard, interview, Langley Field, Va., Jan. 6, 1964. Problems in the sociology of invention, particularly that of simultaneity in discovery or innovation, were compounded many times by the teamwork developmental approach in Mercury. Simplistic views of these matters were embodied in the Mercury capsule contract as well as in certain NASA presentations to Congress which tended to become policy. Some indication of the extent to which credit for innovations ought to be diffused may be gained from the letter, Glenn F. Bailey to J. M. Carson, Jr., "Contract NAS 5-59 Inventions," Sept. 8, 1961.

[40] Jocelyn R. Gill, interview, Houston, Oct. 11, 1965; letter, Gill to members of POISE, Jan. 7, 1963. For a critique of Mercury experimental planning, see letter, Edward P. Ney, Professor of Physics, University of Minnesota, to Gill, Aug. 27, 1962.

[41] "Minutes of the Senior Staff Meeting," MSC, Jan. 4, 1963; "Mercury/Atlas (MA-9) Launch Information and Notebook," General Dynamics/Astronautics, San Diego, undated; C. L. Gandy, Jr., and I. B. Hanson, "Mercury-Atlas Launch Vehicle Development and Performance," in *Mercury Project Summary Including Results of the Fourth Manned Orbital Flight May 15 and 16, 1963,* SP-45 (Washington, 1963), 102.

[42] "Gordon Cooper Press Conference," transcript, MSC, Feb. 8, 1963, 1, 3, 11; Charles M. Vaughn, "Differences Between Spacecraft 16 (MA-8) and Spacecraft 20 (MA-9) as of January 11, 1963," McDonnell Aircraft Corp. Cooper himself had been fully briefed on the MA-9 experiments only four days earlier. See memo, Vaughn to Mercury Project Office, "Minutes . . . of the Mercury Experiments Briefing, MA-9/20," Feb. 13, 1963.

[43] "Manned One-Day Mission—Mission Directive for Mercury/Atlas Mission 9 (MA-9) (Spacecraft No. 20—Atlas 130-D)," NASA Project Mercury working paper No. 232, Feb. 12, 1963, rev. April 25, 1963; Boynton, Edison M. Fields, and Donald F. Hughes, "Spacecraft Systems Development and Performance," in *Mercury Project Summary,* 52. For daily diaries of the technical modifications to each MODM spacecraft at the Cape, see Wilbur Allaback's series of weekly reports to Vogel, of MSC Atlantic Missile Range Engineering Operations, Oct. 1962 to May 1963. For an interesting sidelight on the ECS instrumentation, see William H. Bush, Jr., "$CO_2$ Partial Pressure Measuring System Development," for Mercury Technical History Program, July 23, 1963.

[44] Norman B. Foster, collected documents for Mercury Technical History, "Experiments" folder, Part III, F, May 27, 1963, passim; and Gill interview.

[45] See "Consolidated Activity Report for the Director of Manned Space Flight," MSC, Feb. 23, 1963; Grimwood, *Mercury Chronology,* 158, 167, 180, 183; Ms., Karl F. Greil for Project Mercury Technical History Program, "History of Reaction Control System," July 1963, 12-27; Joe W. Dodson, interview, Houston, March 2, 1965. See also Minutes, "Inflight Scientific Experiments Coordination Panel," Robert B. Voas, secretary, Dec. 17, 1962; Jan. 29, Feb. 25, and March 26, 1963.

[46] "Proceedings of the Mercury-Atlas Booster Reliability Workshop," San Diego, July 12, 1963, 1-56; News release, "Important Mercury-Atlas Refinements," Aerospace Corp., May 6, 1963; "MODM Project Quarterly Status Report No. 18 for Period Ending April 30, 1963," MSC.

[47] "Flight Plan for MA-9/20," March 4, 1963, Rev. A, April 15, 1963; Rev. B, May 10, 1963; "Preparation and Activities Plan for MA-9—Postlaunch Memorandum Report," April 1963; "Public Information Directive," NASA, May 1963; "MA-9 Experiments," SEDR 236, McDonnell Aircraft Corp., April 1, 1963; *Final Report to the Secretary of Defense,* 37, 70, 75. Cf. William K. Douglas, comments, Aug. 17, 1965.

[48] See Philip H. Abelson's editorials in *Science,* CXXXIX (Feb. 1, 1963) and CXL (April 19, 1963). See also John W. Finney, "Astronauts' Camera to Provide TV View of Earth from Space," *New York Times,* April 2, 1963; Howard Simons, "Webb Defends U.S. Men-on-Moon Plan," *Washington Post,* April 21, 1963; Joseph Kraft, "Professors 'Boycott' of Space," Washington *Evening Star,* May 10, 1963; Senate Committee on Aeronautical and Space Sciences, 88 Cong., 1 sess., *Scientists' Testimony on Space Goals,* June 10 and 11, 1963, passim.

[49] "Atlas Repair May Delay Cooper's 22-Orbit Flight," *Washington Post,* April 19, 1963. A Navy physician and NASA official, Frank B. Voris, gave the usual preflight warning for the record: "We can't guarantee 100 percent success, and eventually the odds will catch up with us." Quoted in Allen J. Morrison, "NASA Official Warns of Inevitable Space Tragedy," *Salem* (Oreg.) *Statesman,* April 25, 1963.

[80] The new contingent of astronauts introduced in a televised press conference on Sept. 17, 1962, were assigned specialty areas on Jan. 26, 1963, as follows: Neil A. Armstrong, trainers; Frank Borman, boosters; Charles Conrad, Jr., cockpit; James A. Lovell, Jr., recovery; James A. McDivitt, guidance; Elliot M. See, Jr., electronics; Thomas P. Stafford, communications; Edward H. White II, flight controls; and John W. Young, environmental control. For more details on other allusions in this paragraph, see *Astronautics and Aeronautics, 1963: Chronology on Science, Technology, and Policy,* NASA SP–4004 (Washington, 1964), 28, 69, 184, 190, 192.

[81] Quoted in William Hines, "Cooper to be Out of Contact for Most of 22-Orbit Flight," Washington *Sunday Star,* May 12, 1963. "3-Day Mercury Flight Considered by NASA," *Washington Post,* April 4, 1963. An historical novel based on the plot of what might have happened to MA–10 was written by Martin Caidin, dedicated to Tom Heinsheimer, and published by E. P. Dutton and Co., Inc., in February 1964 under the title *Marooned.* Much authentic flavor of Mercury flight operations may be gleaned from this fictional drama.

[82] See "Astronaut Insured for $100,000," *New York Herald Tribune,* May 9, 1963; S. Oliver Goodman, "Aetna Writes First Astronaut Policies," *Washington Post,* May 9, 1963; "DeOrsey Has Son Write Astronauts' Insurance," Washington *Evening Star,* May 13, 1963; "Cooper Prepares for 22-Orbit Trip," *New York Times,* May 10, 1963; Howard Simons, "Cooper Ready to Take Off; Weather Remains Problem," *Washington Post,* May 14, 1963. Simons also published in the *Post* an excellent series of three articles analyzing the late debate over manned space flight: "Moon Madness? Scientists Divided on Apollo," May 12; "Scientists Now on Sidelines Discontented with Project," May 13; "President Backs Lunar Race Opposed by Some Scientists," May 14, 1963.

[83] Richard Witkin, "Astronaut Flight is Set for Today," *New York Times,* May 15, 1963; Earl Ubell, "The Long and Tense Wait for Astronaut Cooper," *New York Herald Tribune,* May 15, 1963.

[84] Marvin Miles, "Cooper Well on Way to 22 Orbits," *Los Angeles Times,* May 16, 1963; Simons, "Launching Definitely Scheduled: Cooper Set for Another Try," *Washington Post,* May 15, 1963; Hines, "Atlas Boosts Faith-7 Flight As Planned," Washington *Evening Star,* May 15, 1963.

[85] The description and all quotations in the following account of the MA–9 flight are taken directly from the elaborate "Postlaunch Memorandum Report for Mercury-Atlas No. 9 (MA–9): Part I, Mission Analysis; Part II, Data; Part III, Mission Transcripts," MSC, June 24, 1963. For color parallel to the voice transcript, the unedited Mercury Control transcript of John A. Powers' broadcast commentary, "MA–9 Transcript," May 15, 1963, has been followed.

[86] The text of the prayer (taped at time 21:49:38) is as follows:

"I would like to take this time to say a little prayer for all the people, including myself, involved in this launch and this operation. Father, thank You for the success we have had flying this flight. Thank You for the privilege of being able to be in this position, to be up in this wondrous place, seeing all these many startling, wondrous things that You've created. Help guide and direct all of us, that we may shape our lives to be good, that we may be much better Christians, learn to help one another, to work with one another, rather than to fight. Help us to complete this mission successfully. Help us in our future space endeavors, that we may show the world that a democracy really can compete, and still are able to do things in a big way, are able to do research, development, and can conduct various scientific, very technical programs in a completely peaceful environment. Be with all our families. Give them guidance and encouragement, and let them know that everything will be okay. We ask in Thy name. Amen."

[87] See L. Gordon Cooper, Jr., "Everyone Was in a Sweat, I Was Secretly Pleased," *Life,* LIV (June 7, 1963); see also other contract articles: "His Mission Is the Longest U.S. Orbit," *Life,* LIV (May 17, 1963); "He Brings It Right in on the Old Gazoo," *Life,* LIV (May 24, 1963); and "Gordo Gets a Great Hello from the Kids and Kin," *Life,* LIV (May 31, 1963).

[88] "Status Report on Postlaunch Evaluation of Mercury-Atlas Mission No. 9," MSC, May 28, 1963. Quotations are from "MA–9 Press Conference," transcript, May 19, 1963, 7a, 10, 10b.

[89] "MA–9 Scientific Debriefing," transcript, June 26, 1963, 47. Cf. 15. On the skepticism regarding Cooper's vision, see *Aviation Week,* LXXIX (June 17, 1963), 34; (July 1, 1963), 31; and (July 15, 1963), 98. For one of the more important comparative studies of the

astronautical experiences of Glenn, Carpenter, Schirra, and Cooper, see A. Goldberg, L. Hromes, C. E. McLain, and J. Menkes, compilers, "Observations of the Near Wake Reentry Phenomena by the Mercury Astronauts," ARPA TN-64-2, Feb. 1965.

[80] J. C. Jackson, "Manned Space Flight Network Performance Analysis for MA-9," Goddard Space Flight Center publication X-551-63-108, Greenbelt, Md., June 6, 1963, 44. For other details on the results of the fourth manned orbital flight, see *Mercury Project Summary*, 231, 242, and passim.

[81] Webb, interview, Washington, Sept. 3, 1965; Seamans, interview, Washington, Sept. 1, 1965; Senate Committee on Aeronautical and Space Sciences, 88 Cong., 1 sess. (1963), *NASA Authorization for Fiscal Year 1964, Hearings*, Part 2, 772. See also *Scientists' Testimony on Space Goals;* and "Mercury Flights Off, Gemini Comes Next: Astronauts Overruled by NASA," *Houston Chronicle*, June 12, 1963.

## *Epilogue*

[1] McDonnell Aircraft Corp., *NASA Project Gemini Familiarization Manual* (preliminary), SEDR 300, June 1, 1962, passim. See also Ralph O. Shankle, *The Twins of Space* (Philadelphia, 1964); and Charles W. Mathews, "Project Gemini—Status and Plans," paper, 25th annual Aerospace Writers' Assn. Convention, Dallas, Tex., May 24, 1963.

[2] E.g., North American Aviation, Inc., *The Apollo Spacecraft*, Space and Information Systems Division, May 15, 1964; NASA Project Apollo working paper No. 1015, *Project Apollo: Space Task Group Study Report*, February 15, 1961, edited by H. Kurt Strass; NASA MSC fact sheet No. 292, "Apollo Program," June 1965; Walter Sullivan, ed., *America's Race for the Moon: The New York Times Story of Project Apollo* (New York, 1962).

[3] Robert C. Seamans, Jr., Hugh L. Dryden, and James E. Webb, interviews, Washington, D.C., Aug. 31, Sept. 3, 1965.

[4] See *Astronautics and Aeronautics, 1963: Chronology on Science, Technology, and Policy*, NASA SP-4004 (Washington, 1964), 241, 244, 376, 417, 505, 506; and *Astronautics and Aeronautics, 1964: Chronology on Science, Technology, and Policy*, NASA SP-4005 (Washington, 1965), 209, 248.

[5] *Ibid.*, 348, 458; Oscar Theodore Barck, Jr., and Nelson Manfred Blake, *Since 1900: A History of the United States in Our Times* (4th ed., New York, 1965), 877; NASA Office of Educational Programs and Services, pamphlet, "Gemini 4 Extravehicular Activity: A Walk in Space," July 1965.

[6] *Mercury Project Summary, Including Results of the Fourth Manned Orbital Flight, May 15 and 16, 1963*, NASA SP-45 (Washington, 1963).

[7] *Ibid.*, 247-249, part of the paper by J. C. Moser, G. M. Preston, J. J. Williams, and A. E. Morse, Jr.

[8] *Ibid.*, 248. For a similar discussion of quality control for the launch vehicle, see "Manufacturing and Process Controls" in *Proceedings of the Mercury-Atlas Booster Reliability Workshops*, General Dynamics/Astronautics, San Diego, July 12, 1963, 1-56.

[9] See House Committee on Science and Astronautics, 88 Cong., 1 sess. (1963), *Briefing on NASA Reorganization: Project Mercury Summary*, 18-36. See also John W. Finney, "Contractors Cited for an Average of 10 Failures on Each Space Trip," *New York Times*, Oct. 4, 1963; and Edwin Diamond, *The Rise and Fall of the Space Age* (Garden City, N.Y., 1964), 32-46.

[10] Warren Burkett, "NASA Brass Pays Tribute to Industry," *Houston Chronicle*, Oct. 4, 1963; and *New York Times, Washington Post*, and Washington *Evening Star*, Oct. 5, 1963.

[11] See William M. Bland, Jr., and Lewis R. Fisher, "Project Mercury Experience," paper, Aerospace Writers' Assn., Dallas, May 24, 1963; Walter C. Williams, "The Mercury Textbook," paper, American Institute of Aeronautics and Astronautics, Los Angeles, June 17, 1963, MSC fact sheet No. 197; Christopher C. Kraft, Jr., "A Review of Knowledge Acquired from the First Manned Satellite Program," MSC fact sheet No. 206; and Wesley L. Hjornevik, "NASA Programs and Their Management," paper, Harvard Business School Club of Houston, Jan. 28, 1964, MSC fact sheet No. 235.

[12] See *Mercury Project Summary*, 24-26; cf. MSC, "Briefing Materials," prepared for Dr. Robert C. Seamans and Dr. George E. Mueller, Sept. 20-21, 1963 (2 vols., conf.).

[13] *Ibid.*, See also Senate Committee on Aeronautical and Space Sciences, 87 Cong., 2 sess. (1962), Staff Report, *Manned Space Flight Program of the National Aeronautics and Space Administration: Project Mercury, Gemini, and Apollo*, 7.

[14] "Briefing Materials"; Bland and Fisher, and Hjornevik papers.

[15] Fact sheet No. 206, 9. Cf. Robert B. Voas, "The Case History of a Spacecraft (Mercury Project)," MSC fact sheet No. 117, Feb. 5, 1963.

[16] For a few intimations of these questions, see "Our Gamble in Space," special issue of *The Atlantic,* CCXII (August 1963); Lewis Mumford, "Authoritarian and Democratic Technics," *Technology and Culture,* V (Winter 1964), 1–8; Melvin Kranzberg, "The Inner Challenge of Outer Space," paper, University of Houston Lecture-Artist Series, March 3, 1965.

[17] See Alvin M. Weinberg, quoted in James L. Penick, et al., eds., *The Politics of American Science: 1939 to the Present* (Chicago, 1965), 221. See also Weinberg, "Criteria for Scientific Choice," *Minerva* (Winter, 1963), 159–171.

[18] See, for example, Joseph Wood Krutch, "Why I Am Not Going to the Moon," *Saturday Review,* XLVIII (Nov. 20, 1965), 29–31; and Philip H. Abelson, *Saturday Review, idem.*

[19] Hugh L. Dryden, "The Nation's Manned Space Flight," address, Governor's Conference on Oceanography and Astronautics, Kauai, Hawaii, Oct. 1, 1965, 3–4.

# Note on Sources and Selected Bibliography

LATE IN 1962 AND EARLY IN 1963, while Project Mercury was phasing into the Manned One-Day Mission and evolving also toward Projects Gemini and Apollo, the managers of Mercury conceived the need for a monumental technical history to preserve the engineering "experience gained through the development of the Mercury spacecraft, its systems and components." The Director of the Manned Spacecraft Center, Robert R. Gilruth, expressed the hope that an elaborate, topically organized record in 10 or 12 volumes might "provide a ready reference and guide for present and future MSC space programs and to that end [should] increase the economy and effectiveness of MSC operations." Established in February 1963 as the Project Mercury Technical History Program (PMTHP), this effort produced about 40 retrospective manuscripts prepared by participants in Project Mercury. Although more than 130 authors were assigned sections to prepare and only one third of these ever completed their first drafts before reassignment, these manuscripts, located in the archives of the MSC Historian, furnished much of the basis for this technological history of Mercury.

Concurrently in 1963, Eugene M. Emme, the NASA Historian, was prompting the preservation and collection of documentary materials and encouraging all NASA centers and especially the Mercury Project Office of MSC to proceed with the writing of the historical accounts of the technological, managerial, and administrative development of NASA's major programs. Documentary archives for manned space flight, therefore, began first in Washington and then in Houston while Mercury was still alive. The papers and correspondence of Robert R. Gilruth, George M. Low, Paul E. Purser, John A. Powers, and the astronauts' files constitute the bulk of the material presently contained in these two essentially duplicated archives, but innumerable smaller collections on specific technical and operational matters complement and amplify their usefulness.

In May 1963 a contract was arranged between the Manned Spacecraft Center and the University of Houston to provide for professional help to assimilate and synthesize the massive documentary remains from Mercury in several forms suitable for wide distribution as historical literature. The two academic authors of this volume began full-time work immediately after the termination of Mercury,

helping the MSC Historian to complete his *Project Mercury: A Chronology,* NASA SP–4001 (Washington, 1963). Shortly thereafter, an abbreviated and considerably sterilized "PMTHP" was published in one volume as *Mercury Project Summary: Including Results of the Fourth Manned Orbital Flight, May 15 and 16, 1963,* NASA SP–45 (Washington, 1963). These two works are basic reference tools; they are essential to, but not representative of, historical handicraft.

The authors studied Congressional documents; periodicals; secondary literature on space science, technology, and public policy; unclassified governmental, industrial, and military reports; and the artifacts, including audio tapes and photographic records of the program. To orient themselves, they watched sequentially a major portion of more than one million feet of motion picture film, which preserved virtually every significant event and flight operation in Project Mercury.

To maintain some historiographical balance, they sought to subject the widest variety of documents to external (or contextual) and internal scrutiny. Competitive industrial and governmental claims to priorities were weighed. Wherever possible the people who made up the Mercury team were interviewed and each location of Mercury activities visited. Finally the authors concluded that research could proceed most profitably by writing. Concurrent writing and research went on for more than a year, before a "comment edition" was distributed to some 200 critical readers, most of whom found time to offer indispensable suggestions for its improvement.

Footnote readers will have noticed the somewhat different documentary bases of the three parts of this work. Part One rests largely on open (but little used for historical purposes) channels of scientific communication. Part Two is hewn out of a jungle of unpublished technical letters, messages, memoranda, telecon notes, informal reports, and working papers. Part Three is based progressively more on official project documentation, which had improved considerably by that relatively late date.

Unless otherwise specified, all these materials, in original or facsimile form, have been gathered together in the MSC archives. Very few items among those cited in the footnotes are still classified; the vast majority are no longer sensitive and may be examined by students of the early history of manned space flight.

More than 200 personal interviews, 134 Project Mercury working papers, and most of the 4500 typical control and report documents listed in Appendix A of the *Mercury Project Summary* have served as the foundation for this history. The superstructure, however, is selective, as the bibliographical listing also must be. There are many other true tales that need to be placed in survivable form about the technology, administration, public relations, and human side of Project Mercury and the men who worked its wonders. But we authors hope that *This New Ocean* will map the temporal shoreline from which the United States of America cast off on its voyage into space.

## Persons Interviewed*

1. Aldrich, Arnold D.
2. Algranti, Joseph S.
3. Allaback, Wilbur
4. Allen, H. Julian
5. Armstrong, Stephen A.
6. Atcheson, Kenneth L.
7. Bailey, F. John, Jr.
8. Bailey, Glenn F.
9. Battey, Robert V.
10. Berry, Charles A.
11. Billingham, John
12. Bingman, Charles F.
13. Blanchard, Willard S., Jr.
14. Bland, William M., Jr.
15. Bond, Aleck C.
16. Bost, James E.
17. Bothmer, Clyde B.
18. Boyer, William J.
19. Boynton, John H.
20. Briggs, Thomas
21. Brown, B. Porter
22. Burke, Walter F.
23. Butler, Earl
24. Byrnes, Martin A., Jr.
25. Callanan, R. J.
26. Campagna, I. Edward
27. Canning, Thomas N.
28. Canter, Louis
29. Carley, Richard R.
30. Carpenter, M. Scott
31. Catterson, A. Duane
32. Chamberlin, James A.
33. Chambers, Thomas V.
34. Chauvin, Leo T.
35. Chilton, Robert G.
36. Chop, Albert M.
37. Clements, Henry E.
38. Colchagoff, George
39. Coler, Charles
40. Coston, Charles L.
41. Critzos, O. Constance
42. Day, Richard E.
43. Dembling, Paul C.
44. DeVore, Phoncille
45. Dietlein, Lawrence F.
46. Disher, John H.
47. Dodson, Joe W.
48. Donegan, James J., Jr.
49. Donlan, Charles J.
50. Dryden, Hugh L.
51. Dubusker, William
52. Dunham, Richard M.
53. Eppley, Charles V.
54. Erb, R. Bryan
55. Ertel, Ivan
56. Everline, Robert T.
57. Faget, Maxime A.
58. Fields, Edison M.
59. Fineg, Jerry
60. Fisher, Lewis R.
61. Flesh, E. M.
62. Foster, Norman G.
63. Freitag, Robert
64. French, John C.
65. Frutkin, Arnold W.
66. Garland, Benjamine J.
67. Gates, Sally D.
68. Gibbons, Howard I.
69. Gill, Jocelyn R.
70. Gillespie, Ben M.
71. Gilruth, Robert R.
72. Glenn, John H., Jr.
73. Glennan, T. Keith
74. Goldenbaum, David M.
75. Golovin, Nicholas E.
76. Graves, G. Barry

* All are cited in text or footnotes.

77. Gregory, Don T.
78. Gregory, E. M.
79. Grissom, Virgil I.
80. Guice, Mildred L.
81. Hammack, Jerome B.
82. Haney, Paul P.
83. Harris, Gordon
84. Havenstein, Paul L.
85. Heberlig, Jack C.
86. Hicks, Claiborne R., Jr.
87. Hjornevik, Wesley L.
88. Hodge, John D.
89. Hoffman, Sherwood
90. Hohmann, Bernard A.
91. Holmes, Jay
92. Hopko, Russell N.
93. Horsman, Paul F.
94. Hughes, Donald F.
95. Huss, Carl R.
96. Jackson, Bruce G.
97. Johnson, Caldwell C.
98. Johnson, Harold I.
99. Johnson, W. Kemble
100. Jones, Edward R.
101. Keehn, R. W.
102. Kehlet, Alan B.
103. Killmer, George F., Jr.
104. Kleinknecht, Kenneth S.
105. Knauf, George M.
106. Koons, Wayne E.
107. Kraft, Christopher C., Jr.
108. Kuettner, Joachim P.
109. Kyle, Howard C.
110. Lauten, William T., Jr.
111. Lee, John B.
112. Lein, Paul
113. Letsch, Ernst R.
114. Lewis, James L.
115. Link, Mae M.
116. Lord, Douglas R.
117. Low, George M.
118. Lowe, Nancy
119. MacDougall, George F., Jr.
120. MacMillan, Logan T.
121. Manley, Lynn
122. Mardel, A. D.
123. Mathews, Charles W.
124. Mattson, Axel T.
125. Mayer, John P.
126. Maynard, Owen E.
127. McBarron, James W., II
128. McKann, Robert E.
129. McLeaish, John E.
130. McMillion, Lee W.
131. Mercer, Robert D.
132. Meson, John K.
133. Meyer, Andre J., Jr.
134. Miller, Robert R.
135. Minners, Howard A.
136. Morgan, Frank
137. Moseley, W. C., Jr.
138. Muhley, William C.
139. Nagy, Alex P.
140. Niven, John
141. North, Warren J.
142. Oakley, R. B.
143. Olling, Edward H.
144. Ould, J. Wallace
145. Patterson, Herbert G.
146. Pearce, Fred T.
147. Pearson, Albin O.
148. Pepping, Raymond A.
149. Perkins, Kendall
150. Pesman, Gerard J.
151. Peterson, John J.
152. Petynia, William W.
153. Piland, Joseph V.
154. Piland, Robert O.
155. Plohr, H. Warren
156. Powers, John A.
157. Preston, G. Merritt
158. Purser, Paul E.
159. Putnam, William
160. Rashis, Bernard
161. Reitter, L. M.
162. Rhode, Richard V.

163. Ritland, Osmond J.
164. Roberts, Tecwyn
165. Rose, James T.
166. Rose, Rodney G.
167. Rosholt, Robert
168. Samonski, Frank H., Jr.
169. Sandahl, Carl A.
170. Sanderson, Alan H.
171. Seamans, Robert C., Jr.
172. Seat, Robert L.
173. Seiff, Alvin
174. Shankle, Ralph O.
175. Sheldon, Charles S., II
176. Shepard, Alan B., Jr.
177. Shortal, Joseph
178. Siesal, Henry S.
179. Silverstein, Abe
180. Simons, David G.
181. Simpkinson, Scott H.
182. Sjoberg, Sigurd A.
183. Skinner, Francis J.
184. Slayton, Donald K.
185. Soulé, Hartley A.
186. Stapp, John P.
187. Stonesifer, John C.
188. Stoney, William E.
189. Strughold, Hubertus
190. Stuhlinger, Ernst
191. Stullken, D. E.
192. Syverston, C. A.
193. Taylor, Maggie S.
194. Thompson, Robert F.
195. Transue, J. R.
196. Tsitsera, Voula
197. Useller, James W.
198. Vale, Robert E.
199. Van Bockel, John J.
200. Voas, Robert B.
201. Vogel, Kenneth
202. Wagenknecht, Kurt P.
203. Webb, Dalton
204. Webb, James E.
205. Welsh, Edward C.
206. Wendzel, Frank
207. White, D. R.
208. Williams, Walter C.
209. Witunski, Michael
210. Wood, Clotaire
211. Woodling, C. H.
212. Wyatt, DeMarquis D.
213. Yardley, John F.
214. Zoller, Charles E.

# Selected Bibliography

## Basic Reports on Project Mercury

Air Force Space Systems Division TDR-63-381, Sally Anderson, ed., *Final Report: Mercury/Atlas Launch Vehicle Program* (Inglewood, Calif., Nov. 1963)

Air Force Space Systems Division, General Dynamics/Astronautics, and NASA, *Proceedings of the Mercury-Atlas Booster Reliability Workshop* (San Diego, Calif., July 12, 1963)

American Rocket Society, *Space Flight Report to the Nation*, "The Mercury-Redstone Program," paper by Jerome B. Hammack and Jack C. Heberlig (New York, Oct. 9–15, 1961)

Department of Defense Project Mercury Support Operations, *Final Report to the Secretary of Defense on Department of Defense Support of Project Mercury: For the Period 1 July 1959 through 13 June 1963*, Sept. 11, 1963

Fairchild Publications, Inc., *Manned Spacecraft: Engineering, Design, and Operation*, Paul E. Purser, Maxime A. Faget, and Norman F. Smith, eds. (New York, 1964)

International Business Machines Corporation and Western Electric Company, Inc., *Final Report, Project Mercury*, prepared for NASA, March 1, 1962

NASA, *Project Mercury: A Chronology*, by James M. Grimwood, NASA SP–4001 (Washington, 1963)

NASA, *Results of the Project Mercury Ballistic and Orbital Chimpanzee Flights*, James P. Henry and John D. Mosely, eds., NASA SP–39 (Washington, 1963)

NASA, *Space Medicine in Project Mercury*, by Mae Mills Link, NASA SP–4003 (Washington, 1965)

NASA, *Ninth Semiannual Report to Congress, January 1–June 30, 1963*, "Project Mercury in Review" (Washington, 1964)

NASA, *Mercury Project Summary, Including Results of the Fourth Manned Orbital Flight May 15–16, 1963*, NASA SP–45 (Washington, 1963)

*NASA Manned Spacecraft Center, "Postlaunch Memorandum Report for Mercury-Atlas No. 5 (MA–5)," 1961

*NASA Manned Spacecraft Center, "Postlaunch Memorandum Report for Mercury-Atlas No. 6: Part I, Mission Analysis," 1962

*NASA Manned Spacecraft Center, "Postlaunch Memorandum Report for Mercury-Atlas No. 7 (MA–7), Part I, Mission Analysis," 1962

*NASA Manned Spacecraft Center, "Postlaunch Memorandum Report for Mercury-Atlas No. 8: Part I, Mission Analysis," 1962

*NASA Manned Spacecraft Center, "Postlaunch Memorandum Report for MA–8: Part III, Air-Ground Voice and Debriefing," 1962

*NASA Manned Spacecraft Center, "Postlaunch Memorandum Report for Mercury-Atlas No. 9 (MA–9): Part I, Mission Analysis," 1963

*NASA Manned Spacecraft Center, "Postlaunch Memorandum Report for Mercury-Atlas No. 9 (MA–9): Part II, Data," 1963

*NASA Manned Spacecraft Center, "Postlaunch Memorandum Report for Mercury-Atlas No. 9 (MA–9): Part III, Mission Transcripts," 1963

*NASA Manned Spacecraft Center, "Manned One-Day Mission Quarterly Status Report," numbered 17 and 18, 1962–1963

NASA Marshall Space Flight Center, *Final Report, Mercury-Redstone Project–Launch Operations* by Emil P. Bertram and Richard E. Dutton, MSFC–LOD–62–5 (Cape Canaveral, Fla., May 28, 1962)

NASA Marshall Space Flight Center, Saturn-Apollo Systems Office, *The Mercury-Redstone Project*, R. I. Johnson, et al., eds., TMX–53107 (Huntsville, Ala., June 1964)

*NASA Space Task Group/Manned Spacecraft Center, "Project Mercury Quarterly Status Reports," Nos. 1 through 16, 1959–1962

*NASA Space Task Group, "Postlaunch Memorandum Report for Mercury-Redstone No. 4 (MR–4)," 1961

## NASA Project Mercury Working Papers

| WORKING PAPER NO. | |
|---|---|
| 100 | Lunney, Glynn S., "A Study of the Control of Landing Areas for Post Staging Abort Trajectories," August 3, 1959. |
| 101 | "Test No. HS–24 [Big Joe] General Information for Recovery Forces," August 14, 1959. |

* Flight and status reports not listed as Project Mercury working papers.

WORKING PAPER NO.

102 Huss, Carl R., and Lunney, G. S., "Results of Studies Made to Determine Required Retrorocket Capability," September 22, 1959.

103 Hicks, Claiborne R., Jr., and Skopinski, Ted H., "Pre-Stage Abort Studies from the Nominal 105 Nautical Mile Orbital Insertion Trajectory," September 15, 1959.

104 Behuncik, John A., Ferrando, James A., Jr., and Skopinski, T. H., "Preliminary Standard 11-g Type Trajectory—Data for the Early Flights of Mercury-Redstone," September 25, 1959.

105 Graham, John B., Jr., "Recovery Operations for Little Joe Test Number 1-B," February 10, 1960.

106 "Three Degree of Freedom Dynamic Trajectories for 80° and 90° Launch-Pad Abort Conditions with Various Wind Conditions," September 30, 1959.

107 "Preliminary Flight Test Results of the 'Big Joe' Mercury R and D Capsule," October 12, 1959.

108 Hall, John B., Jr., "Qualification Tests on the Big Joe Recovery System," October 27, 1959.

109 Strass, H. Kurt, and Robert, Frank C., "Proposal for a Recoverable Radiation Experiment," November 5, 1959.

110 "Project Mercury Test # HS-24 (XSM-65-10D), Summary of Calculated Preflight Trajectory and Radar Analysis Data," August 31, 1959.

111 Ferrando, J. A., Behuncik, J. A., and Skopinski, T. H., "Mercury-Redstone Separation Distance for Preliminary 11-g Type Trajectory," November 6, 1959.

112 Petynia, William W., and Hasson, Dennis F., "Pretest Report for Off-The-Pad Escape System Qualification Test," March 1, 1960.

113 Hasson, D. F., "Preliminary Study Using Inflatible Spheres for Aerodynamic Stabilization of the Mercury Capsule During Reentry," November 18, 1959.

114 Moseley, William C., Jr., "Summary of the Longitudinal Stability Characteristics of the Little Joe Configurations M=0.05 to M=6.83," December 1, 1959.

115 Windler, Milton L., "Results of Recovery Beacon Test Number 3," December 11, 1959.

116 Skopinski, T. H., Behuncik, J. A., and Ferrando, J. A., Jr., "Mercury-Redstone Abort Study for Preliminary 11-g Type Trajectory," December 15, 1959.

117 Kapryan, Walter J., and Sjoberg, Sigurd A., "Mission Directive for Mercury-Redstone No. 1 [MR-1]," December 15, 1959, Rev. May 20, 1960.

118 Fisher, Lewis R., and Arabian, Donald D., "General Systems Information Document," March 10, 1960.

119 Kyle, Howard C., "Mercury Radio and Command Control System," December 21, 1959.

120 Ferrando, J. A., Behuncik, J. A., and Skopinski, T. H., "Mercury-Redstone Capsule Dispersion Study for Preliminary 11-g Type Trajectory," December 30, 1959.

121 Fisher, L. R., and Chauvin, Leo T., "Mission Document for Little Joe No. 5 (Capsule No. 3)," May 25, 1960.

122 Graham, J. B., Jr., "Recovery Operations for Little Joe Test No. Two," January 18, 1960.

123 Berger, J., "Preliminary Evaluation of Surface Winds at Cape Canaveral," February 19, 1960. [Not released]

124 Moseley, W. C., Jr., "Static Longitudinal Stability Characteristics of the Mercury Capsule Configurations M=0.05 to 20 (Basic Configuration)," March 18, 1960.

125 Windler, M. L., "Results of the Project Mercury HF Recovery Beacon Test No. 1," March 23, 1960.

WORKING PAPER NO.

126 Henry, J. P., "Status of the Animal Test Program," March 31, 1960. [Not released]

127 "Summary of Mercury-Johnsville Centrifuge Program of August 1959," June 22, 1960.

128 Dunseith, Lynwood, and Lunney, G. S., "Methods and Pertinent Data for Project Mercury Flight Computing Requirements," April 6, 1960. [Superseded by working paper 146]

129 Cheatham, Donald C., and Tynan, Charles I., Jr., "General Information for Launch Site Recovery Forces," March 29, 1960.

130 Smith, Robert P., "Static Longitudinal Stability Characteristics of the Mercury Capsule in Combination with the Mercury-Atlas and Mercury-Redstone Boosters M=0.60 to M=3.00," March 28, 1960.

131 Erb, R. Bryan, "Preliminary Study of Heating Aspects of a Radiation Foil Modification to Extend Mercury Heat-Shield Capability to a Natural Decay Entry," April 8, 1960.

132 Arabian, D. D., and Sjoberg, S. A., "Mercury-Atlas (MA-1) Mission Directive (Capsule No. 4)," April 11, 1960.

133 Rose, James T., and Rose, Rodney G., "Research and Development Flight Test Program Using the Little Joe Booster—Booster Qualification Flight Test (Little Joe No. 6)," April 22, 1960.

134 Enderson, Laurence W., Jr., and Rose, R. G., "Research and Development Flight Test Program Using the Little Joe Booster—Abort at High Dynamic Pressure (Little Joe No. 1A)," July 25, 1960.

135 Rose, J. T., and Rose, R. G., "A Method of Estimating Launch Setting to Correct for the Effects of Wind on the Trajectory of a Little Joe Type Vehicle," April 29, 1960. [See TM-X-492]

136 Brumberg, Paul G., "Special Trajectory Parameters for NASA Mercury Missions," April 22, 1960.

137 Jackson, Bruce G., and Williams, Walter E., "Aerodynamic Results of the Little Joe 1-A Flight," May 16, 1960.

138 Kapryan, W. J., and Sjoberg, S. A., "Mission Directive for Mercury-Redstone Mission No. 2 (Capsule No. 5)," April 16, 1960

139 Jones, Enoch M., "General Discussion of Contingency Recovery," May 17, 1960.

140 Arabian, D. D., Fisher, L. R., Sjoberg, S. A., and Hodge, John D., "Mercury-Atlas (MA-2) Mission Directive (Capsule No. 6)," May 27, 1960. [Supplementary to working paper 118]

141 Ferrando, J. A., Jr., and Skopinski, T. H., "Dispersion Study of Separation Distance after Apogee for Mercury-Redstone Preliminary 11-g Type Trajectory," June 8, 1960.

142 Graham, J. B., Jr., and Hodge, B. Leon, "Test No. MA-1: General Information for Recovery Force," July 8, 1960.

143 Hicks, C. R., Jr., and Hunt, Shirley A., "Information for use in Landing Area Prediction for Mercury-Atlas Mission MA-1 (50-D)," July 13, 1960.

144 Huss, C. R., Allen, Charlie, and Hicks, C. R., Jr., "Summary of Calculated Pre-Flight Trajectory Data for MA-1 (Capsule No. 4, Atlas No. 50-D)," July 25, 1960.

145 Hall, J. B., Jr., "Qualification Tests on the MA-1 Terminal System," July 26, 1960.

146 Dunseith, L. C., Lunney, G. S., and Dalby, James F., "Methods and Pertinent Data for Project Mercury Flight Computing Requirements," July 22, 1960. [Supersedes working paper 128, and was superseded by working paper 191]

147 Lewis, John H., Jr., and Mayo, Alfred P., "A Qualitative Description of the Mercury-Atlas Guidance Equations," October 24, 1960.

148 Morse, Archibald E., Jr., and Kranz, Eugene F., "Mission Directive for Mercury-Redstone Mission No. 3 (Capsule No. 7)," September 6, 1960, Rev. March 20, 1961.

WORKING
PAPER NO.

149 McKann, Robert E., and Sjoberg, S. A., "Mission Directive for Mercury-Atlas No. 3 (Capsule No. 8)," October 18, 1960, Rev. March 31, 1961.
150 Weston, Kenneth C., and Swanson, Joanna E., "A Summary of Wind-Tunnel Heat-Transfer Measurements on the Afterbody of the Project Mercury Capsule Reentry Configuration," August 17, 1960. [See TM–X–495, August 1961, for this report]
151 Wheelwright, Charles D., "Animal Ground Support Facilities," August 17, 1960.
152 Patterson, Herbert G., Ewart, David D., and Hamby, William H., "Determination of Mercury Escape Rocket Thrust Eccentricity from Probability Studies of Miss Distance and Lateral Loads During Pre-Staging Abort from Mercury-Atlas Booster," August 19, 1960.
153 Dodson, Joe W., and Kincaide, William C., "Cleveland Window Abrasion Test," August 18, 1960.
154 Maynard, Owen E., "Reconstruction Investigation of Recovered Components from Mercury-Atlas No. 1 After Mission Failure," August 31, 1960.
155 Windler, M. L., "Evaluation of an S-Band Tracking Beacon as a Recovery Location Aid, Test No. 1," September 26, 1960.
156 Skopinski, T. H., Behuncik, J. A., and Ferrando, J. A., Jr., "Calculated Pre-Flight Trajectory Data for Mercury-Redstone Mission No. 1 (MR–1) (Capsule No. 2)," October 10, 1960.
157 Tynan, C. I., Jr., "Test No. MR–1, General Information for Recovery Forces," October 11, 1960.
158 Henry, J. P., "Status of the Animal Test Program," October 20, 1960.
159 Fields, Edison M., and Bond, Aleck C., "Flight Test Report for Mercury-Atlas Mission No. 1 (Capsule No. 4)," November 4, 1960.
160 Huss, C. R., Hartung, Jack B., Hicks, C. R., Jr., and Allen, C. C., "Summary of Several Short Studies Pertaining to the Retro-Rocket System Capability for the Mercury Mission," November 9, 1960.
161 Johnston, Richard S., "Medical Operation Plan," November 4, 1960.
162 Morris, D. P., Jr., "Medical Recovery Operations," October 10, 1960.
163 Hicks, C. R., Jr., O'Loughlin, John C., Allen, C. C., and Huss, C. R., "Summary of Calculated Pre-Flight Trajectory Data for Mercury-Atlas Mission No. 2 (MA–2) (Capsule No. 6, Atlas No. 67–D)," December 7, 1960.
164 Laughlin, C. Patrick, "Bio-Science Data Plan," December 1, 1960.
165 Morris, D. P., Jr., "Medical Recovery Operations (Animal Flights)," October 10, 1960.
166 Chauvin, L. T., and Fisher, L. R., "Flight Test Report for Little Joe Mission No. 5," December 23, 1960.
167 Skopinski, T. H., Maynard, John W., Jr., and Osgood, C. T., "Wind Influence Coefficients for the Mercury-Redstone Missions," January 6, 1961.
168 Skopinski, T. H., Maynard, J. W., Jr., Behuncik, J. A., and Ferrando, J. A., "Calculated Preflight Trajectory Data for Mercury-Redstone Mission No. 2 (MR–2, Capsule No. 5)," January 19, 1961.
169 Kolenkiewicz, Ronald, and Rose, R. G., "Research and Development Flight Test Program Using the Little Joe Booster-High Altitude Abort (Little Joe No. 2)," April 10, 1961.
170 [Enderson, L. W., and Kapryan, W. J., "Post Launch Report for Mercury-Redstone No. 1A (MR–1A)," ca. January 1961; never published]
171 Jackson, C. B., Dr., "Medical Evaluation Program," January 26, 1961.
172 Hermann, Robert A., "Mission Directive for Simulated Orbital Flight Test Program (Capsule No. 10)," February 15, 1961.

WORKING
PAPER NO.

173 Rose, R. G., and Enderson, L. W., "Research and Development Flight Test Program Using the Little Joe Booster, Abort at High Dynamic Pressure (Little Joe No. 1B)," March 3, 1961.

174 Jackson, C. B., McMillion, L. N., and Johnston, R. S., "Astronaut Preparation and Activities Manual for Mercury-Redstone No. 3," February 6, 1961.

175 Mayo, A. P., and Lewis, J. H., Jr., "Mathematical Procedures for Determination of Capsule Range, Azimuth, Elevation, and Radar Look Angles for Pad-Centered and Earth-Centered Inertial Coordinate System," February 15, 1961.

176 Skopinski, T. H., Behuncik, J. A., and Leatherman, P. S., "Preliminary Probability Study of Mercury-Atlas Post-Stage Separation Velocity and Separation Distance After Retrofiring," March 3, 1961.

177 Fisher, L. R., and Chauvin, L. T., "Mission Directive for Little Joe No. 5A (Capsule No. 14)," March 7, 1961.

178 Maynard, J. W., Skopinski, T. H., and Leatherman, P. S., "Calculated Pre-flight Trajectory Data for Redstone Booster Test (MR–BD)," March 17, 1961.

179 Kuehnel, H. A., "Outline for the Astronaut Acceleration Training Program IV," February 24, 1961.

180 Karakulko, Witalij, "Effects of Propellant and Hardware Temperature on the Starting Response Time of $H_2O_2$ Reaction Control Thrust Chambers of the Mercury Capsule," March 9, 1961.

181 Llewellyn, John S., Jr., "Heating Characteristics for Three Mercury Exit Models," March 20, 1961.

182 Samonski, F. H., Jr., and Bush, W. H., Jr., "Environmental Control System Test and Astronaut Training Program," March 3, 1961.

183 Chauvin, L. T., and Fisher, L. R., "Mission Directive for Little Joe No. 5B (Capsule No. 14)," April 7, 1961.

184 "Summary of Calculated Preflight Trajectory Data for Mercury-Atlas Mission No. 3 (MA–3) (Capsule No. 8, Atlas No. 100–D)," April 14, 1961.

185 "Calculated Preflight Trajectory Data for Mercury-Redstone Mission No. 3 (MR–3, Capsule No. 7)," April 20, 1961.

186 Ewart, D. D., and Brown, S. W., "Summary of Dynamic Stability Data for the Mercury Capsule and Escape System," March 22, 1961.

187 "Life Systems Aspects of Third Mercury-Aviation Medical Acceleration Laboratory Centrifuge Program," April 20, 1961.

188 Thompson, W. E., and Pesman, G. J., "Preliminary Appraisal of the Project Mercury Acceleration Hazard," May 15, 1961.

189 Kuehnel, H. A., and Glover, Kenneth E., "Program Description and Discussion for the Astronaut Acceleration Training Program III (Mercury-Redstone Mission Training)," May 8, 1961.

190 Maynard, J. W., Jr., Ferrando, J. A., and Leatherman, P. S., "A Probability Study for Determining Escape-Rocket Thrust Eccentricity for the Mercury-Redstone Missions," May 17, 1961.

191 Dalby, J. F., "Methods and Pertinent Data for Project Mercury Flight Computing Requirements," June 1, 1961. [Supersedes working paper 146]

WORKING PAPER NO.

192 Hammack, J. B., et al., "Post Launch Report for Mercury-Redstone No. 3 (MR–3)," June 16, 1961.

193 Erb, R. B., and Stephens, E. W., "An Analysis of Mercury Heat-Shield Performance During Entry," June 21, 1961.

194 Allen, C. C., and Ferrando, J. A., "Preflight Calculated Tracking Data for the Mercury Network Test Vehicle MNTV–1," June 26, 1961.

195 Fisher, L. R., Chauvin, L. T., and Smith, N. F., "Postlaunch Report for Mercury-Little Joe 5B (LJ–5B)," June 12, 1961.

196 Maynard, J. W., Jr., Behuncik, J. A., and Leatherman, P. S., "Calculated Preflight Trajectory Data for Mercury-Redstone Mission No. 4 (Capsule No. 11)," June 29, 1961.

197 Christopher, Kenneth W., and Kranz, E. F., "Mission Directive for Mercury-Redstone No. 4 (Capsule No. 11)," July 7, 1961.

198 Smith, Norman F., ed., "A Feasibility Study of a Vehicle for 14-Day Orbital Experiments with Animals," July 7, 1961.

199 Hicks, C. R., Jr., O'Loughlin, J. C., and Hunt, S. A., "Tracking and Sighting Data for Stations and Recovery Forces Supporting Mercury-Atlas Mission No. 4," July 7, 1961.

200 Allen, C. C., and Ferrando, J. A., "Summary of Calculated Preflight Trajectory Data for the Mercury Network Test Vehicle MNTV–1," July 12, 1961.

201 Fisher, L. R., "Mission Directive for Mercury-Scout Mission No. 1 (MS–1)," July 21, 1961.

202 Winterhalter, David L., "Determination of Net Thrust of Project Mercury Tower Jettison Rocket and Escape Tower Assembly," July 3, 1961.

203 Gergory, D. T., and Kranz, E. F., "Mission Directive for Mercury-Atlas No. 4 (Capsule No. 8A)," July 28, 1961.

204 Hicks, C. R., Jr., O'Loughlin, J. C., and Hunt, S. A., "Calculated Preflight Trajectory Data for Mercury-Atlas Mission No. 4 (Capsule No. 8A, Atlas No. 88–D)," August 2, 1961.

205 Hartung, Jack B., and Wetmore, Warren C., "A Composite Model Atmosphere for Use in Project Mercury Calculations," September 29, 1961.

206 Zedekar, Raymond G., "Astronaut Preparation for Orbital Flight," October 13, 1961.

207 Hicks, C. R., Jr., and Allen, C. C., "Calculated Preflight Trajectory Data for Mercury-Atlas Mission 5 (MA–5) (Capsule 9—Atlas 93–D)," October 19, 1961.

208 Gregory, D. T., and von Ehrenfried, M. H., "Mission Directive for Mercury-Atlas Mission No. 5 (Capsule No. 9)," October 20, 1961.

209 Hammack, J. B., et al., "Postlaunch Report for Mercury-Redstone No. 4 (MR–4) (Capsule 11)," September 22, 1961.

210 Skopinski, T. H., Ferrando, J. A., and Osgood, C. T., "Postlaunch Trajectory Report for Mercury-Redstone Mission 3 (MR–3, Capsule 7)," October 12, 1961.

211 Skopinski, T. H., Behuncik, J. A., and Leatherman, P. S., "Postlaunch Trajectory Report for Mercury-Redstone Mission 4 (MR–4, Capsule 11)," October 16, 1961.

212 Hicks, C. R., Jr., Allen, C. C., and O'Loughlin, J. C., "Calculated Preflight Abort Trajectory Data and Nominal Trajectory Display Data for MA Mission 5 (MA–5) (Capsule 9, Atlas 93–D)," November 6, 1961.

213 Fields, Edison M., et al., "Postlaunch Report for Mercury-Atlas Mission 4 (MA–4, Capsule 8A)," November 10, 1961.

214 O'Loughlin, J. C., and Leonard, Pauline O., "Tracking and Sighting Data for Stations

WORKING
PAPER NO.

and Recovery Forces Supporting Mercury-Atlas Mission No. 6 (MA-6—Spacecraft 13)," December 13, 1961.

215 McCutcheon, Ernest P., Morris, D. P., McBarron, James W., II, and McMillion, L. N., "Astronaut Preparation and Activities Manual for Mercury-Atlas Mission 6 (MA-6—Spacecraft 13)," December 1, 1961.

216 Christopher, K. W., and Kranz, E. F., "Mission Directive for Mercury-Atlas Mission 6 (MA-6—Spacecraft 13)," December 15, 1961.

217 Hicks, C. R., Jr., and O'Loughlin, J. C., "Calculated Preflight Trajectory Data for Mercury-Atlas Mission 6 (MA-6) (Atlas 109-D—Spacecraft 13)" (Addendum To W. P. Nos. 207 and 212), December 28, 1961.

218 "Addendum Data Report for Mercury-Atlas Mission 4 (MA-4—Spacecraft 8A)," November 29, 1961.

219 Hartung, J. B., "Analysis of Conditions Determining the Transition Regime Between Ballistic and Orbital Flight for Project Mercury," January 9, 1962.

220 Fields, E. M., Everline, Robert T., Jr., Arbic, R. G., Donnelly, Paul C., Sjoberg, S. A., Smith, N. F., and White, S. C., "Postlaunch Report for Mercury-Atlas Mission 5 (MA-5—Spacecraft 9) Part I—Mission Analysis," March 9, 1962.

221 Everline, R. T., Jr., "Postlaunch Report for Mercury-Atlas Mission 5 (MA-5—Spacecraft 9) Part II—Data," March 9, 1962.

222 Boynton, John H., von Ehrenfried, M., "Mission Directive for Mercury-Atlas Mission 7 (MA-7—Spacecraft 18)," April 9, 1962.

223 Everline, R. T., Jr., Fisher, L. R., Bost, James E., Piland, Joseph V., Bland, William M., and Kleinknecht, K. S., "Manned One-Day Mission Mercury Spacecraft Specification Document," April 23, 1962, Rev. 1963.

224 Hicks, C. R., Jr., and Allen, C. C., "Calculated Preflight Trajectory Data for Mercury-Atlas Mission 7 (MA-7) (Spacecraft 18—Atlas 107-D)," May 4, 1962.

225 Hicks, C. R., Jr., Allen, C. C., and O'Loughlin, J. C., "Calculated Preflight Abort Trajectory Display Data and Nominal Trajectory Display Data for Mercury-Atlas Mission 7 (MA-7) (Spacecraft 18—Atlas 107-D)," May 4, 1962.

226 McCutcheon, E. P., Morris, D. P., and McBarron, J. W., II, "Astronaut Preparation and Activities Manual for Orbital Flight," April 10, 1962.

227 Jacobs, Stanley, and Stephens, E. W., "Experimental Results and Analysis of Ablation Tests Performed on Project Mercury Heat Shield Segments in a Langley Research Center Structures Division ARC Facility," May 23, 1962.

228 Boynton, J. H., and Kranz, E. F., "Mission Directive for Mercury-Atlas Mission No. 8 (MA-8—Spacecraft 16)," August 31, 1962.

229 Allen, C. C., Hicks, C. R., Jr., and Bostick, Jerry C., "Calculated Preflight Trajectory Data for Mercury-Atlas Mission 8 (MA-8) (Spacecraft No. 16—Atlas 113-D)," September 7, 1962.

230 Incerto, Donald J., McCreary, Ben F., and Osgood, C. T., "Postlaunch Trajectory Report for Mercury-Atlas Mission No. 4 (MA-4) (Spacecraft No. 8A—Atlas 88-D) and for Mercury-Atlas Mission No. 5 (MA-5) (Spacecraft No. 9—Atlas 93-D)," October, 1962.

231 St. Leger, Leslie G., "Design Study of a Meteoroid Experiment Using an Unmanned Mercury Spacecraft," December 27, 1962.

232 Boynton, J. H., and Kranz, E. F., "Manned One-Day Mission—Mission Directive for Mercury-Atlas Mission 9 (MA-9—Spacecraft 20)," February 12, 1963, Rev. April 25, 1963.

233 Bostick, J. C., and Carter, Thomas F., Jr., "Calculated Preflight Trajectory Data for

WORKING PAPER NO.

the Manned One-Day Mercury-Atlas Mission (MA-9) (Spacecraft No. 20—Atlas 130-D)," March 15, 1963.

234 Bostick, J. C., and Carter, T. F., Jr., "Calculated Preflight Abort Trajectory Data and Flight Dynamics Display Data for the Manned One-Day Mercury-Atlas Mission (MA-9) (Spacecraft No. 20—Atlas 130-D)," April 16, 1963.

235 Geier, Douglas J., Slight, John B., Marak, Ralph J., and Turner, Thomas, "The Development and Qualification Testing of a Lightweight Net Couch and Restraint System for Use in the Mercury Spacecraft" [Never published].

## Bibliographical Aids

American Institute of Aeronautics and Astronautics (AIAA), *International Aerospace Abstracts* (Phillipsburg, N.J., 1961—).

Catoe, Lynn E., compiler, *Space Science and Technology Books 1957–1961: A Bibliography with Contents Noted* (Washington, Library of Congress, 1962).

Estep, Raymond, *An Aerospace Bibliography*, Documentary Research Division, Research Studies Institute, Air University (Maxwell Air Force Base, Alabama, 1962—).

Gamble, William B., compiler, *History of Aeronautics: A Selected List of References to Material in the New York Public Library* (New York, 1938).

Gibbs-Smith, Charles H., *The History of Flying*, Reader's Guides, Second Series 9 (Cambridge, England, National Book League, 1957).

Ley, Willy, *Rockets, Missiles, and Space Travel*, revised and enlarged edition (New York, 1957), Bibliography, 489–520.

Moore, Patrick, *Space Exploration*, Reader's Guides, Third Series (Cambridge, England, National Book League, 1958).

National Aerospace Education Council, *Aeronautics and Space Bibliography of Adult Aerospace Books and Materials* (2 ed., Washington, 1964).

National Aeronautics and Space Administration, *Historical Sketch of NASA*, NASA EP-29 (Washington, 1965), Select Historical References, 51–56.

National Aeronautics and Space Administration, *List of Selected References on NASA Programs*, NASA SP-3 (Washington, Library of Congress, 1962).

National Aeronautics and Space Administration, *Scientific and Technical Aerospace Reports (STAR): A Semimonthly Abstract Journal with Indexes* (Washington, 1963—).

National Aeronautics and Space Administration, *Space Scientists and Engineers: Selected Biographical and Bibliographical Listing, 1957–1961*, NASA SP-5 (Washington, 1962).

Renstrom, Arthur G., "Bibliographical Note," in E. M. Emme, ed., *The History of Rocket Technology* (Detroit, 1964), 285–308.

## Official Reports and Documents

Army Air Forces Scientific Advisory Group, *Toward New Horizons: A Report to General of the Army H. H. Arnold* (14 vols., Washington, 1945).

Congress, House, Committee on Appropriations, Subcommittee on Independent Offices, *Hearings* and *Reports* (Washington, 1959–1963).

———, Committee on Government Operations, *Hearings* and *Reports* (Washington, 1959–1963).

———, Committee on Science and Astronautics (née Select Committee), *Hearings* and *Reports* (1959–1965).

Congress, Senate, Committee on Aeronautical and Space Sciences (née Special Committee), *Hearings* and *Reports* (Washington, 1958–1965).

———, Committee on Armed Services, Preparedness Subcommittee (85 Cong., 1 and 2 sess.), *Hearings: Inquiry into Satellite and Missile Programs* (Washington, 1957–1958).

———, Committee on Appropriations, *Hearings* and *Reports* (Washington, 1959–1963).

Department of State, *Documents on International Aspects of the Exploration and Use of Outer Space 1954–1962* (Washington, Senate Doc. No. 18, May 9, 1963).

———, *International Cooperation and Organization for Outer Space* (Washington, Senate Doc. No. 56, Aug. 12, 1965).

National Academy of Sciences—National Research Council, *I.G.Y. Bulletin* (Washington, 1957–1963).

———, Space Science Board, *A Review of Space Research* (Washington, Pub. 1079, 1962).

National Advisory Committee for Aeronautics, *Annual Reports, 1923–1958* (Washington, 1924–1959).

National Aeronautics and Space Administration, *Aeronautical and Astronautical Events of 1961* (Washington, House Committee on Science and Astronautics, 1962).

———, *Astronautical and Aeronautical Events of 1962* (Washington, House Committee on Science and Astronautics, 1963).

———, *Astronautics and Aeronautics: Chronology on Science, Technology, and Policy, 1963, 1964, 1965* (Washington, 1964–1966).

———, *Proceedings of NASA-Industry Program Plans Conferences* (Washington, 1960, 1963).

———, *Proceedings of National Conferences on Peaceful Uses of Space*, 1961–1965 (Washington, 1961–1966).

———, *Semiannual Reports, 1959–1964* (Washington, 1960–1965).

———, Manned Spacecraft Center, *Results of the Second U.S. Manned Suborbital Space Flight, July 21, 1961* (Washington, 1961).

———, Manned Spacecraft Center, *Results of the First U.S. Manned Orbital Space Flight, February 20, 1962* (Washington, 1962).

———, Manned Spacecraft Center, *Results of the Second United States Manned Orbital Space Flight, May 24, 1962*, NASA SP-6 (Washington, 1962).

———, Manned Spacecraft Center, *Results of the Third United States Manned Orbital Space Flight, October 3, 1962*, NASA SP-12 (Washington, 1962).

National Aeronautics and Space Administration, National Institutes of Health, and National Academy of Sciences, *Conference on Medical Results of the First U.S. Manned Suborbital Space Flight: A Compilation of Papers Presented* (Washington, 1961).

Smithsonian Institution, *Annual Reports, 1955–1962* (Washington, 1956–1963).

White House, *U.S. Aeronautical and Space Activities*, annual report with message of the President (Washington, 1959–1966).

## Books

Adams, Carsbie C., *Space Flight: Satellites, Spaceships, Space Stations, and Space Travel Explained* (New York, 1958).

*Advances in Astronautical Sciences: Proceedings of Third Annual Meeting, American Astronautical Society* (New York, 1957).

Akens, David S., *Historical Origins of the George C. Marshall Space Flight Center* (Huntsville, Ala., 1960).

———, Paul K. Freiwirth, and Helen T. Wells, *History of the George C. Marshall Space Flight Center* (Huntsville, Ala., 1960–1962).

Alexander, Tom, *Project Apollo: Man to the Moon* (New York, 1964).

Allen, John E., *Aerodynamics: A Space-Age Survey* (New York, 1963).

Allen, William H., ed., *Dictionary of Technical Terms for Aerospace Use*, NASA SP–7 (Washington, 1965).

Alperin, Morton, M. Stern, and H. Wooster, eds., *Vistas in Astronautics: First Annual Astronautics Symposium* (London, 1958).

Armstrong, Harry G., *Principles and Practices of Aviation Medicine* (3 ed., Baltimore, 1952).

Army Ordnance Corps/General Electric Co., *Hermes Guided Missile Research and Development Project, 1944–1954* (1959).

Bailey, James O., *Pilgrims Through Space and Time: Trends and Patterns in Scientific and Utopian Fiction* (New York, 1957).

Baker, Robert M. L., and Maud W. Makemson, *An Introduction to Astrodynamics* (New York, 1960).

Barashev, Pavel, and Yuri Dokuchayev, *Gherman Titov: First Man to Spend a Day in Space* (New York, 1962).

Bates, D. R., *The Earth and Its Atmosphere* (New York, 1957).

Baxter, James P., *Scientists Against Time* (Boston, 1946).

Bell, Joseph N., *Seven into Space: The Story of the Mercury Astronauts* (Chicago, 1960).

Benecke, Theodore, and A. W. Quick, eds., *History of German Guided Missile Development* (Brunswick, Germany, 1957).

Benson, Otis O., and Hubertus Strughold, eds., *Physics and Medicine of the Atmosphere and Space* (New York, 1960).

Bergaust, Erik, *First Men in Space* (New York, 1960).

———, *Rocket City, U.S.A.: From Huntsville, Ala., to the Moon* (New York, 1963).

———, and Seabrook Hull, *Rocket to the Moon* (Princeton, N.J., 1958).

Bergman, Jules, *Ninety Seconds to Space: The Story of the X–15* (New York, 1960).

Berkner, Lloyd V., *The Scientific Age* (New Haven, 1964).

———, and Hugh Odishaw, eds., *Science in Space* (New York, 1961).

Besserer, C. W., and Hazel C., eds., *Guide to the Space Age* (Englewood Cliffs, N.J., 1959).

Blagonravov, A. H., ed., *Collected Works of K. E. Tsiolkovsky: II, Reactive Flying Machines*, NASA TT F–237 (Washington, 1965).

Blasingame, Benjamin P., *Astronautics* (New York, 1964).

Bloomfield, Lincoln P., ed., *Outer Space: Prospects for Man and Society* (Englewood Cliffs, N.J., 1962).

Bonney, Walter T., *Heritage of Kitty Hawk* (New York, 1962).

Branley, Franklyn M., *Exploring by Astronaut: The Story of Project Mercury* (New York, 1961).

Bridgeman, William, and Jacqueline Hazard, *The Lonely Sky* (New York, 1955).

Bunker, George M., et al., *The Missile Industry—In Defense and the Exploration of Space* (Baltimore, 1961).

Bush, Vannevar, *Modern Arms and Free Men* (New York, 1949).

Caidin, Martin, *The Astronauts: The Story of Project Mercury, America's Man-in-Space Program* (New York, 1960).

———, *Rendezvous in Space* (New York, 1962).

———, *The Man-in-Space Dictionary: A Modern Glossary* (New York, 1963).

———, and Grace Caidin, *Aviation and Space Medicine: Man Conquers the Vertical Frontier* (New York, 1962).

Cameron, A. G. W., ed., *Interstellar Communication: A Collection of Reprints and Original Contributions* (New York, 1963).

Carter, L. J., ed., *Realities of Space Travel: Selected Papers of the British Interplanetary Society* (New York, 1957).
Chapman, John L., *Atlas: The Story of a Missile* (New York, 1960).
Clarke, Arthur C., *The Exploration of Space* (New York, 1959).
———, et al., *Man and Space* (New York, 1964).
Cleator, P. E., *Rockets Through Space* (London, 1936).
*Collected Papers on Aviation Medicine, Presented at Aeromedical Panel Meetings of the Advisory Group for Aeronautical Research and Development, North Atlantic Treaty Organization* (London, 1955).
Committee on Extension the Standard Atmosphere, *U.S. Standard Atmosphere, 1962* (Washington, 1962).
Cooke, David C., *Flights that Made History* (New York, 1960).
Coombs, Charles I., *Project Mercury* (New York, 1960).
Cov, Donald W., *The Space Race: From Sputnik to Apollo and Beyond* (Philadelphia, 1962).
———, and Michael Stoiko, *Spacepower: What It Means to You* (Philadelphia, 1958).
Craven, Wesley F., and James L. Cate, eds., *History of the Army Air Forces in World War II* (7 vols., Chicago, 1948–1955).
Crossfield, A. Scott, and Clay Blair, *Always Another Dawn: The Story of a Rocket Test Pilot* (Cleveland, 1960).
Davis, Clive E., *Man and Space* (New York, 1960).
Davy, M. J. B., *Interpretative History of Flight* (London, 1948).
De Leeuw, Henrik, *Conquest of the Air: The History and Future of Aviation* (New York, 1960).
Department of the Air Force, *German Aviation Medicine, World War II* (2 vols., Washington, 1950).
Diamond, Edwin, *The Rise and Fall of the Space Age* (Garden City, N.Y., 1964).
Dille, John, ed., *We Seven, by the Astronauts Themselves* (New York, 1962).
Dornberger, Walter R., *V–2* (New York, 1954).
Duke, Neville, and Edward Lanchbery, *The Saga of Flight: From Leonardo da Vinci to the Guided Missile: An Anthology* (New York, 1961).
Dupree, A. Hunter, *Science in the Federal Government: A History of Policies and Activities to 1940* (Cambridge, Mass., 1957).
Durand, William F., *Aerodynamic Theory: A General Review of Progress* (2 ed., 6 vols. in 3, New York, 1963).
Ehricke, Krafft, *Space Flight* (3 vols., Princeton, N.J., 1960).
Eisenhower, Dwight D., *The White House Years: Waging Peace, 1956–1961* (Garden City, N.Y., 1965).
Ellul, Jacques, *The Technological Society* (New York, 1964).
Emme, Eugene M., *Aeronautics and Astronautics: An American Chronology of Science and Technology in the Exploration of Space, 1915–1960* (Washington, 1961).
———, ed., *The History of Rocket Technology: Essays on Research, Development, and Utility* (Detroit, 1964).
———, *A History of Space Flight* (New York, 1965).
———, ed., *The Impact of Air Power: National Security and World Politics* (Princeton, N.J., 1959).
Eppley, Charles V., *The Rocket Research Aircraft Program, 1946–1962* (Edwards Air Force Base, Calif., 1962).
Esnault-Pelterie, Robert, *L'Astronautique* (Paris, 1930).
Etzioni, Amitai, *The Moon-Doggle: Domestic and International Implication of the Space Race* (Garden City, N.Y., 1964).
Faget, Maxime A., *Manned Space Flight* (New York, 1965).
Feodosiev, V. I., and G. B. Siniarev, *Introduction to Rocket Technology*, trans. S. N. Samburoff (New York, 1959).
*The First Man In Space: The Record of Yuri Gagarin's Historic First Venture Into Cosmic Space: A Collection of Translations from Soviet Press Reports* (New York, 1961).

Flaherty, Bernard E., ed., *Psychophysiological Aspects of Space Flight* (New York, 1961).
*Fortune*, editors of, *The Space Industry: America's Newest Giant* (Englewood Cliffs, N.J., 1962).
Freudenthal, Elsbeth E., *The Aviation Business: From Kitty Hawk to Wall Street* (New York, 1940).
———, *Flight into History: The Wright Brothers and the Air Age* (Norman, Okla., 1949).
Frutkin, Arnold W., *International Cooperation in Space* (Englewood Cliffs, N.J., 1965).
Gantz, Kenneth F., ed., *Man in Space: The United States Air Force Program for Developing the Spacecraft Crew* (New York, 1959).
———, ed., *The United States Air Force Report on the Ballistic Missile* (New York, 1958).
Gartmann, Heinz, *The Men Behind the Space Rockets* (New York, 1956).
Gatland, Kenneth W., *Development of the Guided Missile* (2 ed., London, 1954).
———, *Spacecraft and Boosters: The First Comprehensive Analysis of More than 70 United States and Soviet Union Launchings to 1961* (London, 1964).
Gavin, James M., *War and Peace in the Space Age* (New York, 1958).
Gaynor, Frank, *Aerospace Dictionary* (New York, 1960).
Gerathewohl, Siegfried J., *Principles of Bioastronautics* (Englewood Cliffs, N.J., 1963).
Gibbs-Smith, Charles H., *The Aeroplane* (London, 1960).
———, *The History of Flying* (New York, 1954).
Gibney, Frank, ed., *The Penkovsky Papers*, trans. Peter Deriabin (Garden City, N.Y., 1965).
——— and George F. Feldman, *The Reluctant Spacefarers: A Study in the Discovery of Politics* (New York, 1965).
Glasstone, Samuel, *Sourcebook on the Space Sciences* (Princeton, N.J., 1965).
Goddard, Robert H., *Rocket Development: Liquid Fuel Rocket Research, 1921–1941*, ed., E. C. Goddard and G. Edward Pendray (Englewood Cliffs, N.J., 1948).
———, *Rockets: Comprising "A Method of Reaching Extreme Altitudes" and "Liquid-Propellant Rocket Development"* (New York, 1946).
Godwin, Felix, *The Exploration of the Solar System* (New York, 1960).
Goodwin, Harold L., *Image of Space* (New York, 1965).
Gordon, Theodore I., and Julian Scheer, *First in Outer Space* (New York, 1959).
Gove, Philip B., *The Imaginary Voyage in Prose and Fiction: A History of Its Criticism and a Guide to Its Study . . .* (New York, 1961).
Gray, George W., *Frontiers of Flight: The Story of NACA Research* (New York, 1948).
Green, Roger L., *Into Other Worlds: Space-Flight from Lucian to Lewis* (New York, 1958).
Grey, Jerry and Vivian, eds., *Space Flight Report to the Nation* (New York, 1962).
Griffith, Alison E., *The National Aeronautics and Space Act: A Study of the Development of Public Policy* (Washington, 1962).
Grimminger, George, *Analysis of Temperature, Pressure, and Density of the Atmosphere Extending to Extreme Altitudes* (Santa Monica, Calif., 1948).
Gubitz, Myron B., *Rocketship X–15* (New York, 1962).
Gurney, Gene, *Americans Into Orbit: The Story of Project Mercury* (New York, 1962).
Haber, Heinz, *Man in Space* (New York, 1953).
Hale, Edward Everett, *The Brick Moon and Other Stories* (Boston, 1899).
Haley, Andrew G., *Rocketry and Space Exploration* (Princeton, N.J., 1958).
Hall, A. R., *The Scientific Revolution, 1500–1800: The Foundation of the Modern Scientific Attitude* (Boston, 1954).
Hanrahan, James H., and David Bushnell, *Space Biology: The Human Factors in Space Travel* (New York, 1960).
Hartt, Julian, *The Mighty Thor: Missile in Readiness* (New York, 1961).
Henry, James P., *Biomedical Aspects of Space Flight* (New York, 1965).
Hewlett, Richard G., and Oscar E. Anderson, Jr., *The New World: 1939–1946: A History of the Atomic Energy Commission* (1 vol. to date, University Park, Pa., 1962 —).
Hoff, Nicholas J., and Walter G. Vincenti, eds., *Aeronautics and Astronautics: Proceedings of the*

*Durand Centennial Conference Held at Stanford University 5–8 August 1959* (New York, 1960).
Holley, I. B., Jr., *Ideas and Weapons: Exploitation of the Aerial Weapon by the U.S. During World War I* (New Haven, 1953).
———, *Buying Aircraft: Materiel Procurement for the Army Air Forces* (Washington, 1964).
Holmes, Jay, *America on the Moon: The Enterprise of the Sixties* (Philadelphia, 1962).
Horowitz, Paul, ed., *Manned Space Reliability Symposium*, Vol. 1 of American Astronautical Society Science and Technology Series (New York, 1964).
Howard-White, F. B., *Nickel: An Historical Review* (New York, 1963).
Hunsaker, Jerome C., *Aeronautics at Mid-Century* (New Haven, 1952).
Huzel, Dieter K., *Peenemünde to Canaveral* (Englewood Cliffs, N.J., 1962).
Jastrow, Robert, ed., *The Exploration of Space* (New York, 1960).
Jensen, Jorgen, et al., *Design Guide to Orbital Flight* (New York, 1962).
Jessup, Philip C., and Howard J. Taubenfeld, *Controls for Outer Space and the Antarctic Analogy* (New York, 1959).
Jones, Bessie Z., *Lighthouse in the Sky: History of the Smithsonian Astrophysical Observatory* (Washington, 1965).
Kast, Freemont E., and James E. Rosenzweig, eds., *Science, Technology, and Management* (New York, 1963).
Keyhoe, Donald E., *Flying Saucers in Outer Space* (New York, 1954).
Korol, Alexander G., *Soviet Research and Development: Its Organization, Personnel and Funds* (Cambridge, Mass., 1965).
Kosmodemyansky, A., *Konstantin Tsiolkovsky, His Life and Work*, trans. X. Danko (Moscow, 1956).
Koyré, Alexander, *From the Closed World to the Infinite Universe* (paperback ed., New York, 1958).
Krieger, F. J., ed., *A Casebook on Soviet Astronautics* (2 vols., Santa Monica, Calif., 1956–1957)
———, ed., *The Men Behind the Sputniks* (Washington, 1958).
Lapp, Ralph E., *Man and Space: The Next Decade* (New York, 1961).
Le Galley, Donald P., ed., *Ballistic Missile and Space Technology* (4 vols., New York, 1960).
Lear, John, *Kepler's Dream* (Berkeley, Calif., 1965).
Lees, Sidney, ed., *Air, Space, and Instruments: Draper Anniversary Volume* (New York, 1963).
Lehman, Milton, *This High Man: The Life of Robert H. Goddard* (New York, 1963).
Lerner, Max, *The Age of Overkill: A Preface to World Politics* (New York, 1962).
Levy, Lillian, ed., *Space: Its Impact on Man and Society* (New York, 1965).
Ley, Willy, *Rockets, Missiles, and Space Travel* (3 rev. ed., New York, 1961).
Lindbergh, Charles A., *The Spirit of St. Louis* (New York, 1955).
———, *We: The Famous Flyer's Own Story of His Life and His Transatlantic Flight, Together with His Views on the Future of Aviation* (New York, 1927).
Link, Mae Mills, *Space Medicine in Project Mercury*, NASA SP–4003 (Washington, 1965).
——— and Hubert A. Coleman, *Medical Support of the Army Air Forces in World War II* (Washington, 1955).
Loosbrock, John F., ed., *Space Weapons: A Handbook of Military Astronautics* (New York, 1959).
McCormick, Ernest J., *Human Factors Engineering* (2 ed., New York, 1964).
McFarland, Marvin W., ed., *The Papers of Wilbur and Orville Wright* (2 vols., New York, 1953).
Mallan, Lloyd, *Men, Rockets and Space Rats* (rev. ed., New York, 1962).
———, *Man into Space* (New York, 1960).
Medaris, John B., *Countdown for Decision* (New York, 1960).
Menzel, Donald H., *Flying Saucers* (Cambridge, Mass., 1953).
Michael, Donald N., et al., *Proposed Studies on the Implications of Peaceful Space Activities for Human Affairs* (Washington, 1961).
Morris, Lloyd, and Kendall Smith, *Ceiling Unlimited: The Story of American Aviation from Kitty Hawk to Supersonics* (New York, 1953).
Murchie, Guy, *Music of the Spheres* (Boston, 1961).

Myrus, Don, *The Astronauts* (New York, 1960).
———, *Keeping Up with the Astronauts: The Story of Man's Greatest Adventures in Outer Space* (New York, 1962).
Neal, Roy, *Ace in the Hole: The Story of the Minuteman Missile* (Garden City, N.Y., 1962).
Newell, Homer E., *High Altitude Rocket Research* (New York, 1953).
———, *Sounding Rockets* (New York, 1959).
Nicolson, Marjorie Hope, *Science and Imagination* (Ithaca, N.Y., 1956).
———, *Voyages to the Moon* (paperback ed., New York, 1960).
Niven, John, Courtlandt Canby, and Vernon Welsh, eds., *Dynamic America: A History of General Dynamics Corporation and Its Predecessor Companies* (Garden City, N.Y., 1960).
Oberth, Hermann, *Man into Space: New Projects for Rocket and Space Travel*, trans. G. P. H. De Freville (New York, 1957).
Odishaw, Hugh, ed., *The Challenges of Space* (Chicago, 1962).
Ordway, Frederick I., III, James P. Gardner, and Mitchell R. Sharpe, Jr., *Basic Astronautics: An Introduction to Space Science, Engineering and Medicine* (Englewood Cliffs, N.J., 1962).
———, James P. Gardner, Mitchell R. Sharpe, Jr., and Ronald Wakeford, *Applied Astronautics: An Introduction to Space Flight* (Englewood Cliffs, N.J., 1963).
Ossenbeck, Frederick I., and Patricia C. Kroeck, *Open Space and Peace: A Symposium on Effects of Observation* (Stanford, Calif., 1964).
Ostlin, Melvin T., *Thinking Out Loud About the Space Age: Is the Christian Faith Adequate for a Space Age?* (Philadelphia, 1962).
Parry, Albert, *Russia's Rockets and Missiles* (Garden City, N.Y., 1960).
Parson, Nels A., Jr., *Guided Missiles in War and Peace* (Cambridge, Mass., 1956).
———, *Missiles and the Revolution in Warfare* (Cambridge, Mass., 1962).
Peck, Merton J., and Frederic M. Scherer, *The Weapons Acquisition Process: An Economic Analysis* (Boston, 1962).
Pendray, G. Edward, *The Coming Age of Rocket Power* (New York, 1945).
Penick, J. L., Jr., and C. W. Pursell, Jr., M. B. Sherwood, and Donald C. Swain, eds., *The Politics of American Science: 1939 to the Present* (Chicago, 1965).
Petrov, V., *Artificial Satellites of the Earth*, trans. B. S. Sharma (Delhi, 1960).
Piccard, Auguste, *Between Earth and Sky*, trans. Claude Apcher (London, 1950).
———, *Earth, Sky and Sea*, trans. Christine Stead (New York, 1956).
Pierce, Philip N., and Karl Schuon, *John H. Glenn, Astronaut* (New York, 1962).
Poole, Lynn, and Gray Poole, *Scientists Who Work with Astronauts* (New York, 1964).
Pope, Alan, *Wind-Tunnel Testing* (2 ed., New York, 1954).
Price, Derek J., de Solla, *Little Science, Big Science* (New York, 1963).
Price, Don K., *Government and Science: Their Dynamic Relation in American Democracy* (New York, 1962).
Ramo, Simon, ed., *Peacetime Uses of Outer Space* (New York, 1961).
Randers-Pehrson, N. H., *History of Aviation* (New York, 1944).
Rechtschaffen, Oscar H., ed., *Reflections on Space: Its Implications for Domestic and International Affairs* (Colorado Springs, Colo., 1964).
Ritner, Peter, *The Society of Space* (New York, 1961).
Rosen, Milton W., *The Viking Rocket Story* (New York, 1955).
Rosenthal, Alfred, *The Early Years: Goddard Space Flight Center Historical Origins and Activities Through December 1962* (Washington, 1964).
Rosholt, Robert L., *An Administrative History of NASA, 1958–1963*, NASA SP–4101 (Washington, 1966).
Sänger, Eugen, *Rocket Flight Engineering* (Munich, 1933), NASA Tech. Trans. F–223 (Washington, 1965).
———, *Space Flight: Countdown for the Future*, trans. Karl Frucht (New York, 1965).
Schlaifer, Robert, and S. D. Heron, *Development of Aircraft Engines and Development of Aviation*

*Fuels: Two Studies of Relations between Government and Business* (Boston, 1950).
Schwiebert, Ernest G., *A History of the U.S. Air Force Ballistic Missiles* (New York, 1965).
Seifert, Howard S., ed., *Space Technology* (New York, 1959).
Shankle, Ralph O., *The Twins of Space* (Philadelphia, 1964).
Shelton, William R., *Countdown: The Story of Cape Canaveral* (Boston, 1960).
Shternfeld, Ari, *Soviet Space Science* (2nd rev. ed., New York, 1959).
Simon, Leslie G., *German Research in World War II: An Analysis of the Conduct of Research* (New York, 1947).
Simons, S. Fred, ed., *Progress in the Astronautical Sciences* (Amsterdam, 1962).
Skinner, Richard M., and William Leavitt, eds., *Speaking of Space: The Best From Space Digest* (Boston, 1962).
Slager, Ursula T., *Space Medicine* (Englewood Cliffs, N.J., 1962).
Smith, R. W., and J. W. Altman, *Space Psychology: Some Considerations in the Study of Astronauts' Behavior* (Pittsburgh, 1961).
Stehling, Kurt, *Project Vanguard* (Garden City, N.Y., 1961).
Stillwell, Wendell H., *X–15 Research Results with Selected Bibliography*, NASA SP–60 (Washington, 1965).
Stiltz, Harry L., ed., *Aerospace Telemetry* (Englewood Cliffs, N.J., 1961).
Stover, Carl F., ed., *The Technological Order: Proceedings of the Encyclopedia Britannica Conference* (Detroit, 1963).
Strughold, Hubertus, *The Green and Red Planet: A Physiological Study of the Possibility of Life on Mars* (Albuquerque, 1953).
Struve, Otto, and Velta Zeergs, *Astronomy of the 20th Century* (New York, 1962).
Stuhlinger, Ernst, Frederick I. Ordway, III, Jerry C. McCall, and George C. Bucher, eds., *From Peenemünde to Outer Space: Commemorating the Fiftieth Birthday of Wernher von Braun* (Huntsville, Ala., 1962).
Sullivan, Walter, *Assault on the Unknown: The International Geophysical Year* (New York, 1961).
———, ed., *America's Race for the Moon: The New York Times Story of Project Apollo* (New York, 1962).
Taubenfeld, Howard J., ed., *Space and Society: Studies for the Seminar on Problems of Outer Space* sponsored by the Carnegie Endowment for International Peace (Dobbs Ferry, N.Y., 1964).
Thomas, Shirley, *Men of Space* (7 vols., Philadelphia, 1960–1965).
———, *Satellite Tracking Facilities: Their History and Operation* (New York, 1963).
Titov, Gherman, *700,000 Kilometres Through Space* (Moscow, 1962).
——— and Martin Caidin, *I Am Eagle!* (Indianapolis, 1962).
Vaeth, J. Gordon, *200 Miles Up: The Conquest of the Upper Air* (2 ed., New York, 1956).
Van Dyke, Vernon, *Pride and Power: The Rationale of the Space Program* (Urbana, 1964).
Von Kármán, Theodore, *Aerodynamics: Selected Topics in the Light of Their Historical Development* (Ithaca, N.Y., 1954).
Von Mises, Richard, *Theory of Flight* (2 ed., New York, 1959).
Wainwright, Loudon, and the seven astronauts, *The Astronauts* (New York, 1961).
Waters, Frank, *Robert Gilruth: Engineering Space Exploration* (Chicago, 1963).
White, Clayton S., and Otis O. Benson, eds., *Physics and Medicine of the Upper Atmosphere: A Study of the Aeropause* (Albuquerque, 1952).
White, William J., *A History of the Centrifuge in Aerospace Medicine* (Santa Monica, Calif., 1964).
Wilks, Willard E., *The New Wilderness: What We Know About Space* (New York, 1963).
Williams, Beryl, and Samuel Epstein, *The Rocket Pioneers on the Road to Space* (New York, 1955).
Wise, David, and Thomas B. Ross, *The U–2 Affair* (New York, 1962).
Witkin, Richard, ed., *The Challenge of the Sputniks* (Garden City, N.Y., 1958).
Zaehringer, Alfred J., *Soviet Space Technology* (New York, 1961).
Zarem, Lewis, *New Dimensions of Flight* (New York, 1959).

JOURNAL ARTICLES

Abbot, Charles G., "The Relations Between the Smithsonian Institution and the Wright Brothers," *Smithsonian Miscellaneous Collections*, LXXXI (Sept. 29, 1928).

Alexander, George, "Atlas Accuracy Improves as Test Program is Completed," *Aviation Week*, LXXVIII (Feb. 25, 1963).

Allen, H. Julian, "Hypersonic Flight and the Reentry Problem," *Journal of the Aeronautical Sciences*, XXV (April 1958).

Anderton, David S., "How Mercury Capsule Design Evolved," *Aviation Week*, LXXIV (May 22, 1961).

Andrews, W. H., "Contributions from the X–15 Flight Test Program," *Society of Experimental Test Pilots' Quarterly Review*, V (Sept. 29, 1961).

Armstrong, Harry G., Heinz Haber, and Hubertus Strughold, "Aero Medical Problems of Space Travel, Panel Meeting, School of Aviation Medicine," *Journal of Aviation Medicine*, XX (Dec. 1949).

Baker, Normal L., "Air Force Won't Support Project Adam," *Missiles and Rockets*, III (June 1958).

Ballinger, E. R., "Human Experiments in Subgravity and Prolonged Acceleration," *Journal of Aviation Medicine*, XXIII (Aug. 1952).

Beach, Edward L., "Triton Follows Magellan's Wake," *National Geographic*, CXVIII (Aug. 1960).

Becker, John V., "The X–15 Project: Part I: Origins and Research Background," *Astronautics and Aeronautics*, II (Feb. 1964).

Berry, Charles A., "The Environment of Space in Human Flight," *Aeronautical Engineering Review*, XVII (March 1958).

Beyer, David H., and Saul B. Sells, "Selection and Training of Personnel for Space Flight," *Journal of Aviation Medicine*, XXVIII (Feb. 1957).

Bonney, Walter T., "High-Speed Research Airplanes," *Scientific American*, CLXXXIX (Oct. 1953).

Clark, B., and Ashton Graybiel, "The Break-Off Phenomenon," *Journal of Aviation Medicine*, XXVII (April 1957).

Clark, Carl C., and James D. Hardy, "Preparing Man for Space Flight," *Astronautics*, IV (Feb. 1959).

Clark, Evert, "NASA Centralizes Launch Management," *Aviation Week*, LXXII, (May 30, 1960).

Clarke, Arthur C., "Rocket to the Renaissance," *Playboy*, VII (July 1960).

———, "Space Travel in Fact and Fiction," *British Interplanetary Society Journal*, IX (Sept. 1960).

Colchagoff, George D., "Outline of History of USAF Man-In-Space Research and Development Program," Air Force information policy letter supplement No. 109, Aug. 1962, *Missiles and Rockets*, X (March 26, 1962).

Dixon, Thomas F., "Development Problems of Rocket Engines for Ballistic Missiles," *Interavia*, LXXI (1959).

Donlan, Charles J., and Jack C. Heberlig, "Progress Report on Project Mercury," *Astronautics*, V (Aug. 1960).

Drake, F. D., "Project OZMA," *Physics Today*, XIV (April 1961).

Dryden, Hugh L., "Fact-Finding for Tomorrow's Planes," *National Geographic*, CIV (Dec. 1953).

———, "NACA: What It's Doing and Where It's Going," *Missiles and Rockets*, I (Oct. 1956).

———, "Space Technology and the NACA," *Aeronautical Engineering Review*, XVII (March 1958).

———, "Future Exploration and Utilization of Outer Space," *Technology and Culture* (Spring 1961).
———, "Toward The New Horizons of Tomorrow: First Annual ARS von Kármán Lecture," *Astronautics*, VIII (Jan. 1963).
———, "Footprints on the Moon," *National Geographic*, CXXV (March 1964).
"Dyna-Soar's History Full of Re-Examinations," *Aviation Week*, LXXXVII (July 22, 1963).
Eggers, Alfred J., Jr., "Performance of Long Range Hypervelocity Vehicles," *Jet Propulsion*, XXVII (Nov. 1957).
Eggleston, John M., "Some Abort Techniques and Procedures for Manned Spacecraft," *Aerospace Engineering*, XXI (Nov. 1962).
Emme, Eugene M., "The Impact of Air Power Upon History," *Air University Quarterly Review*, II (Winter 1948).
———, "Yesterday's Dream, Today's Reality," *Airpower Historian*, VII (Oct. 1960).
Faget, Maxime, and Robert O. Piland, "Mercury Capsule and Its Flight Systems," *Aerospace Engineering*, XIX (April 1960).
Ferri, Antonio, Lewis Feldman, and Walter Daskin, "The Use of Lift for Reentry from Satellite Trajectories," *Jet Propulsion*, XXVII (Nov. 1957).
Fisher, Allen C., Jr., "Aviation Medicine on the Threshold of Space," *National Geographic*, CVI (Aug. 1955).
———, "Cape Canaveral's 6000-Mile Shooting Gallery," *National Geographic*, CXVI (Oct. 1959).
———, "Exploring Tomorrow with the Space Agency," *National Geographic*, CXVII (July 1960).
"Flight of the MR–3," *Missiles and Rockets*, VIII (May 15, 1961).
Gatland, Kenneth W., "The Vanguard Project," *Spaceflight*, I (Oct. 1956).
Gerathewohl, Siegfried J., "Physics and Psychophysics of Weightlessness and Visual Perception," *Journal of Aviation Medicine*, XXV (1954).
———, "Weightlessness: The Problem and the Air Force Research Program," *Air University Quarterly Review*, XIV (Oct. 1950).
———, and G. R. Steinkamp, "Human Factors Requirements for Putting a Man into Orbit," *Astronautica Acta*, V (1959).
Gibbs-Smith, Charles H., "The Wright Brothers and Their Invention of the Practical Airplane," *Nature*, CXCVII (June 1, 1963).
Glennan, T. Keith, "Opportunities for International Cooperation in Space Exploration," *U.S. Dept. of State Bulletin* (Jan. 11, 1960).
———, "Space Exploration," *Vital Speeches* (April 16, 1960).
Graybiel, Ashton, et al., "An Account of Experiments in Which Two Monkeys Were Recovered Unharmed After Ballistic Space Flight," *Aerospace Medicine*, XXX (Dec. 1959).
Grether, Walter F., "Psychology and the Space Frontier," *American Psychologist*, XVII (Feb. 1962).
Grimminger, George, "Probability That a Meteorite Will Hit or Penetrate a Body Situated in the Vicinity of the Earth." *Journal of Applied Physics*, XIX (Oct. 1948).
Haber, Fritz, and Heinz Haber, "Possible Methods of Producing the Gravity-Free State for Medical Research," *Journal of Aviation Medicine*, XXI (Oct. 1950).
Hagemann, E. R., "Goddard and His Early Rockets, 1882–1930," *Journal of the Astronautical Sciences*, VII (Summer 1961).
Hall, R. Cargill, "Origins and Development of the Vanguard and Explorer Satellite Programs," *Airpower Historian*, XI (Oct. 1964).
Hanson, C. Frederick, "The Characteristics of the Upper Atmosphere Pertaining to Hypervelocity Flight," *Jet Propulsion*, XXVII (Nov. 1957).
Henry, James P., et al., "Animal Studies of the Subgravity State During Rocket Flight," *Journal of Aviation Medicine*, XXIII (Oct. 1952).

"How Mercury Capsule Design Evolved," *Aviation Week*, LXX (Sept. 21, 1959).
Kennedy, John F., "If the Soviets Control Space They Can Control Earth," *Missiles and Rockets*, VII (Oct. 10, 1960).
Kittinger, Joseph W., "The Long, Lonely Leap," *National Geographic*, CXVIII (Dec. 1960).
Kousnetzov, Andrei G., "Some Results of Biological Experiments in Rockets and Sputnik II," *Journal of Aviation Medicine*, XXIX (Nov. 1958).
Krause, Ernst, "High Altitude Research with V-2 Rockets," *Proceedings of the American Philosophical Society*, XCI (1947).
Lear, John, "The Moon That Refused to be Eclipsed," *Saturday Review*, XLIII (March 5, 1960).
Leavitt, William, "The Weird World of Weightlessness," *Air Force*, XLII (April 1959).
Lees, Lester, "Laminar Heat Transfer Over Blunt-Nosed Bodies at Hypersonic Flight Speeds," *Jet Propulsion*, XXVI (April 1956).
———, "Recent Developments in Hypersonic Flow," *Jet Propulsion*, XXVII (Nov. 1957).
Martin, James A., "The Record-Setting Research Airplanes," *Aeronautical Engineering Review*, XXI (Dec. 1962).
Maxwell, W. R., "Some Aspects of the Origin and Early Development of Astronautics," *Journal of British Interplanetary Society*, XVIII (Sept. 1962).
Means, P., "Mercury Instrumentation: Pilot's Fate Depends on Seven Miles of Wiring," *Missiles and Rockets*, VI (June 13, 1960).
Mohler, Stanley R., "Wiley Post's Aerospace Achievements," *Airpower Historian*, XI (July 1964).
North, Gilbert B., "Development and Checkout of the NASA Mercury Capsule," *Canadian Aeronautical Journal*, VII (Feb. 1961).
Oates, Stephen B., "NASA's Manned Spacecraft Center at Houston, Texas," *Southwestern Historical Quarterly*, LXVII (Jan. 1964).
Oberth, Hermann, "From My Life," *Astronautics*, IV (June 1959).
Pendray, G. Edward, "The First Quarter Century of the American Rocket Society," *Jet Propulsion*, XXV (Nov. 1955).
Piccard, Jacques, "Man's Deepest Dive," *National Geographic*, CXVIII (July 1960).
Pierce, Roger J., "Mercury Capsule Communications," *Astronautics*, IV (Dec. 1959).
Rae, John B., "Financial Problems of the American Aircraft Industry," *Business History Review*, XXXIX (Spring 1965).
———, "Science and Engineering in the History of Aviation," *Technology and Culture*, II (Fall 1961).
Ritland, Osmond J., "Concurrency," *Air University Quarterly Review*, XII (Winter-Spring 1960–61).
Ritzinger, Frederick R., Jr., and Ellis G. Aboud, "Pressure Suits—Their Evolution and Development," *Air University Quarterly Review*, XVI (Jan.–Feb. 1965).
Schiff, L. I., "A Report on the NASA Conference on Experimental Test of Theories of Relativity," *Physics Today*, XIV (Nov. 1961).
Sheehan, Robert, "Thompson Ramo Wooldridge: Two Wings in Space," *Fortune*, LXVII (Feb. 1963).
Simons, David G., "The 1954 Aeromedical Field Laboratory Balloon Flights: Physiological and Radiobiological Aspects," *Journal of Aviation Medicine*, XXVII (April 1956).
———, "Psychophysiological Aspects of Manhigh," *Astronautics*, IV (Feb. 1959).
———, "Review of Biological Effects of Subgravity and Weightlessness," *Jet Propulsion*, XXV (May 1955).
———, "Space Medicine—The Human Body in Space," *Journal of the Franklin Institute Series*, monograph No. 6 (Dec. 1958).
———, and C. H. Steinmetz, "Physiological and Radiobiological Aspects of 1954 Aeromedical Field Laboratory Balloon Flight," *Journal of Aviation Medicine*, XXVI (1955).

Singer, S. Fred, "The Use and Uselessness of Outer Space," *Reporter*, XX (June 11, 1959).
Solomon, Philip, et al., "Sensory Deprivation, A Review," *Americal Journal of Psychology*, CXIV (Oct. 1957).
Spiegel, F. S., "Changing Concepts in Physical Standards for Flying," *Aerospace Medicine*, XXXI (Nov. 1960).
Stalder, Jackson R., "A Survey of Heat Transfer Problems Encountered by Hypersonic Aircraft," *Jet Propulsion*, XXVII (Nov. 1957).
Stapp, John P., "Acceleration: How Great a Problem?" *Astronautics*, IV (Feb. 1959).
Strughold, Hubertus, "Atmospheric Space Equivalence," *Journal of Aviation Medicine*, XXV (Aug. 1954).
———, "An Introduction to Astrobiology," *Astronautics*, V (Dec. 1960).
———, "The Medical Problems of Space Flight," *International Record of Medicine*, CLXVIII (1955).
———, "A Simple Classification of the Present and Future Stages of Manned Flight," *Journal of Aviation Medicine*, XXVII (Aug. 1956).
———, "Space Equivalent Conditions," *Astronautica Acta*, I (1955).
———, "The U.S. Air Force Experimental Sealed Cabin," *Journal of Aviation Medicine*, XXVII (Feb. 1956).
———, Heinz Haber, Konrad Buettner, and Fritz Haber, "Where Does Space Begin? Functional Concept of the Boundaries Between Atmosphere and Space," *Aviation Medicine*, XXII (Oct. 1951).
Sweeney, Robert, "Atlas Generates Fabrication Advances," *Aviation Week*, LXXII (Jan. 4, 1960).
———, "Manufacturing the Atlas at Convair," *Interavia*, LXXI (1959).
Thompson, G. V. E., "Oberth—Doyen of Spaceflight Today," *Spaceflight*, I (Oct. 1957).
Toll, Thomas A., and Jack Fischel, "The X–15 Project: Results and New Research," *Astronautics and Aeronautics*, II (March 1964).
Tsiolkovsky, Konstantin E., "An Autobiography," trans. A. N. Petroff, *Astronautics*, IV (May 1959).
Useller, James W., and Joseph S. Algranti, "Pilot Reaction to High Speed Rotation," *Aerospace Medicine*, XXXIV (June 1963).
"USAF School Simulates Living in Space," *Aviation Week*, LXVIII (Jan. 27, 1958).
Van der Wal, F. L., and W. D. Young, "Project MIA (Mouse-in-Able), Experiments on Psychological Response to Space Flight," *Jet Propulsion*, XXXI (Oct. 1959).
Victory, J. F., "The NACA: Cradle of Research," *Flying*, LX (March 1957).
Voas, Robert B., "A Description of the Astronaut's Task in Project Mercury," *Human Factors*, III (Sept. 1961).
Von Beckh, Harald J., "Human Reactions During Flight to Acceleration, Preceded by or Followed by Weightlessness," *Aerospace Medicine*, XXX (June 1959).
———, "Multidirectional G-Protection in Space Vehicles," *Journal of the British Interplanetary Society*, XVI (Sept.–Oct. 1958).
Walker, Joseph A., "I Fly the X–15," *National Geographic*, CXXII (Sept. 1962).
Ward, Julian E., Willard R. Hawkins, and Herbert D. Stallings, "Physiologic Response to Subgravity, I: Mechanics of Nourishment and Deglutination of Solids and Liquids," *Journal of Aviation Medicine*, XXX (March 1959).
———, Willard R. Hawkins, and Herbert D. Stallings, "Physiologic Response to Subgravity, II: Initiation of Micturition," *Aerospace Medicine*, XXX (Aug. 1959).
Weaver, Kenneth F., "Countdown for Space," *National Geographic*, CXIX (May 1961).
Webb, James E., "International Relations and Space," *Vital Speeches* (Oct. 1, 1961).
———, "New Age of Discovery," *Airpower Historian*, XI (July 1964).
Westbrook, C. B., "The Pilot's Role in Space Flight," *Aerospace Engineering*, XVIII (Nov. 1959).

Weyl, A. R., "Gravity and the Prospects for Astronautics," *Aeronautics*, XXXIX (Feb. 1959).
Williams, Walter C., and Hubert M. Drake, "The Research Airplane: Past, Present, and Future," *Aeronautical Engineering Review*, XVII (Jan. 1958).

### Unpublished Works

Ambrose, Mary Stone, "The National Space Program," M.A. thesis, 2 vols., American University, 1961.
[Blount, Earl E., Jr.], Special Communications Staff, North American Aviation, Inc., "Comment on the National Space Program: 'Pro and Con'," Vol. III, No. 1, Sept. 1, 1964 [Vol. I—July 1, 1963; Vol. II—Sept. 1, 1963].
Bullard, John A., "History of the Redstone Missile System," AMC 23M, Army Missile Command, 1965.
Bushnell, David, "History of Research in Subgravity and Zero-G at the Air Force Missile Development Center, 1948–1959," Air Force Missile Development Center, 1959.
———, "Major Achievements in Biodynamics: Escape Physiology at the Air Force Missile Development Center, 1953–1958," Air Force Missile Development Center, 1959.
———, "Major Achievements in Space Biology at the Air Force Missile Development Center, 1953–1957," Air Force Missile Development Center [1958].
———, "The Sacramento Peak Observatory, 1947–1962," Air Force Office of Aerospace Research, 1962.
"Chronology of Early USAF Man-in-Space Activity, 1945–1958," Air Force Systems Command [1965].
"Chronology of Early Air Force Man-in-Space Activity, 1955–1960," Air Force Systems Command [1965].
Lasby, Clarence G., "German Scientists in America: Their Importation, Exploitation, and Assimilation, 1945–1952," Ph.D. dissertation, University of California at Los Angeles, 1962.
Levine, Arthur S., "United States Aeronautical Research Policy, 1915–1958: A Study of the Major Policy Decisions of the National Advisory Committee for Aeronautics," Ph.D. dissertation, Columbia University, 1963.
Peyton, Green, and Jean Evans, "History, Aerospace Medical Division, Air Force Systems Command: Reorganization, 1 November 1951–30 June 1962," Brooks Air Force Base, Tex., 1962.
Whipple, Marven R., "History of the Air Force Missile Test Center," Patrick Air Force Base, Fla., 1957.

### Postflight Reports

*Proceedings of a Conference on Results of the First U.S. Manned Suborbital Space Flight*, United States National Aeronautics and Space Administration in Cooperation with National Institutes of Health and National Academy of Sciences (Washington, 1961).
*Results of the Second U.S. Manned Suborbital Space Flight, July 21, 1961*, Manned Spacecraft Center, National Aeronautics and Space Administration (Washington, 1961).
*Results of the First United States Manned Orbital Space Flight, February 20, 1962*, Manned Spacecraft Center, National Aeronautics and Space Administration (Washington, 1962).
*Results of the Second United States Manned Orbital Space Flight, May 24, 1962*, National Aeronautics and Space Administration, Manned Spacecraft Center, Project Mercury, NASA SP-6 (Washington, 1962).
*Results of the Third United States Manned Orbital Space Flight, October 3, 1962*, National Aeronautics and Space Administration, Manned Spacecraft Center, Project Mercury, NASA SP-12 (Washington, 1962).

*Mercury Project Summary Including Results of the Fourth Manned Orbital Flight, May 15 and 16, 1963*, National Aeronautics and Space Administration, Manned Spacecraft Center, Project Mercury, NASA SP–45 (Washington, 1963).

*"Postlaunch Memorandum Report for Mercury-Redstone No. 4 (MR–4)," (NASA Space Task Group, 1961).

*"Postlaunch Memorandum Report for Mercury-Atlas No. 5 (MA–5)," (NASA Manned Spacecraft Center, 1961).

*"Postlaunch Memorandum Report for Mercury-Atlas No. 6: Part I, Mission Analysis," (NASA Manned Spacecraft Center, 1962).

*"Postlaunch Memorandum Report for Mercury-Atlas No. 7 (MA–7), Part I, Mission Analysis," (NASA Manned Spacecraft Center, 1962).

*"Postlaunch Memorandum Report for Mercury-Atlas No. 8: Part I, Mission Analysis," (NASA Manned Spacecraft Center, 1962).

*"Postlaunch Memorandum Report for MA–8: Part III, Air-Ground Voice and Debriefing," (NASA Manned Spacecraft Center, 1962).

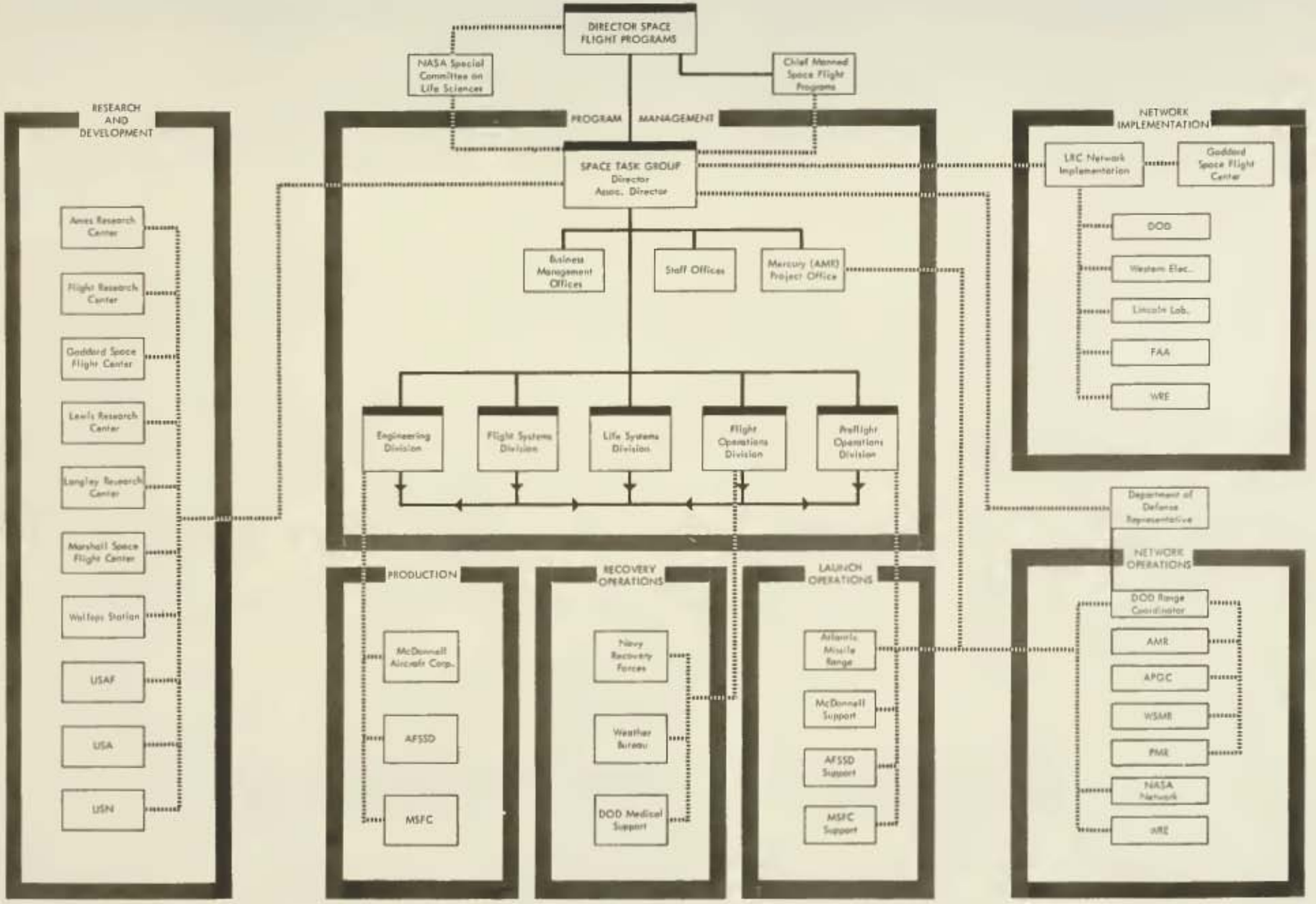
*"Postlaunch Memorandum Report for Mercury-Atlas No. 9 (MA–9): Part I, Mission Analysis," (NASA Manned Spacecraft Center, 1963).

*"Postlaunch Memorandum Report for Mercury-Atlas No. 9 (MA–9): Part II, Data," (NASA Manned Spacecraft Center, 1963).

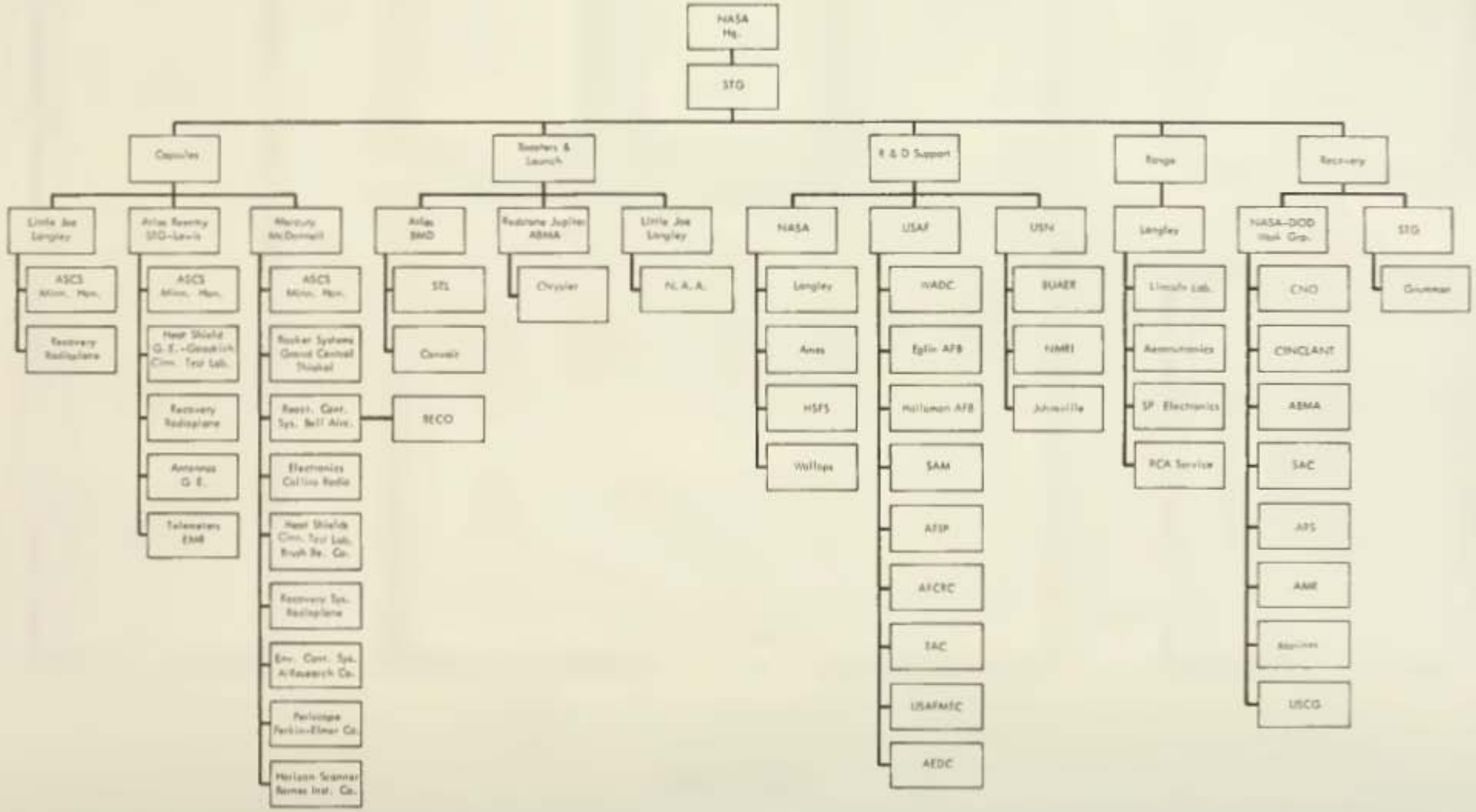
*"Postlaunch Memorandum Report for Mercury-Atlas No. 9 (MA–9: Part III, Mission Transcripts," (NASA Manned Spacecraft Center, 1963).

*Classified flight reports not listed as Project Mercury Working Papers.

# Appendix A: Functional Organization of Mercury

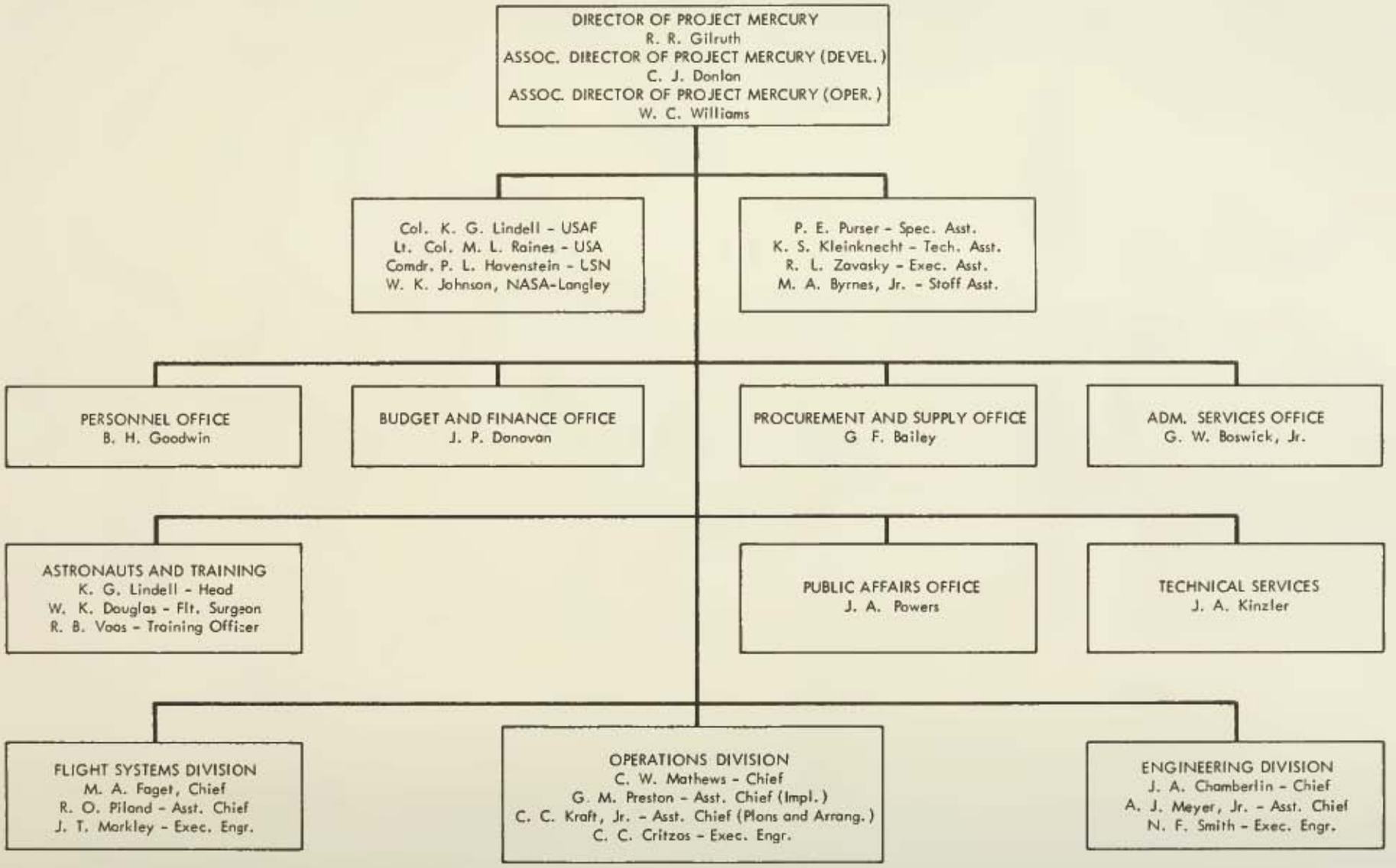


# Appendix B
# Workflow Organization of Mercury



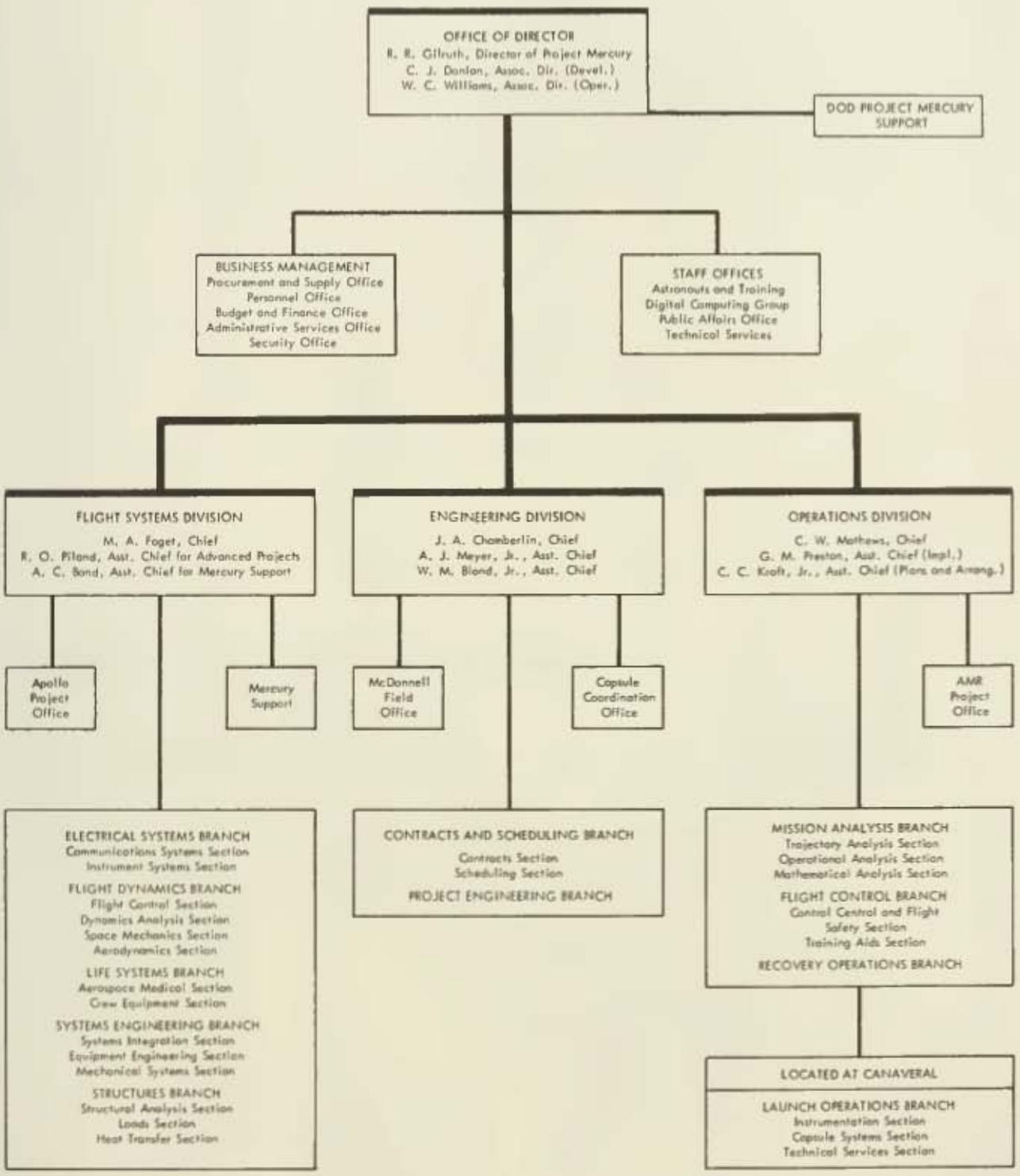
# Appendix C
# Organization Charts

# SPACE TASK GROUP
## August 1959



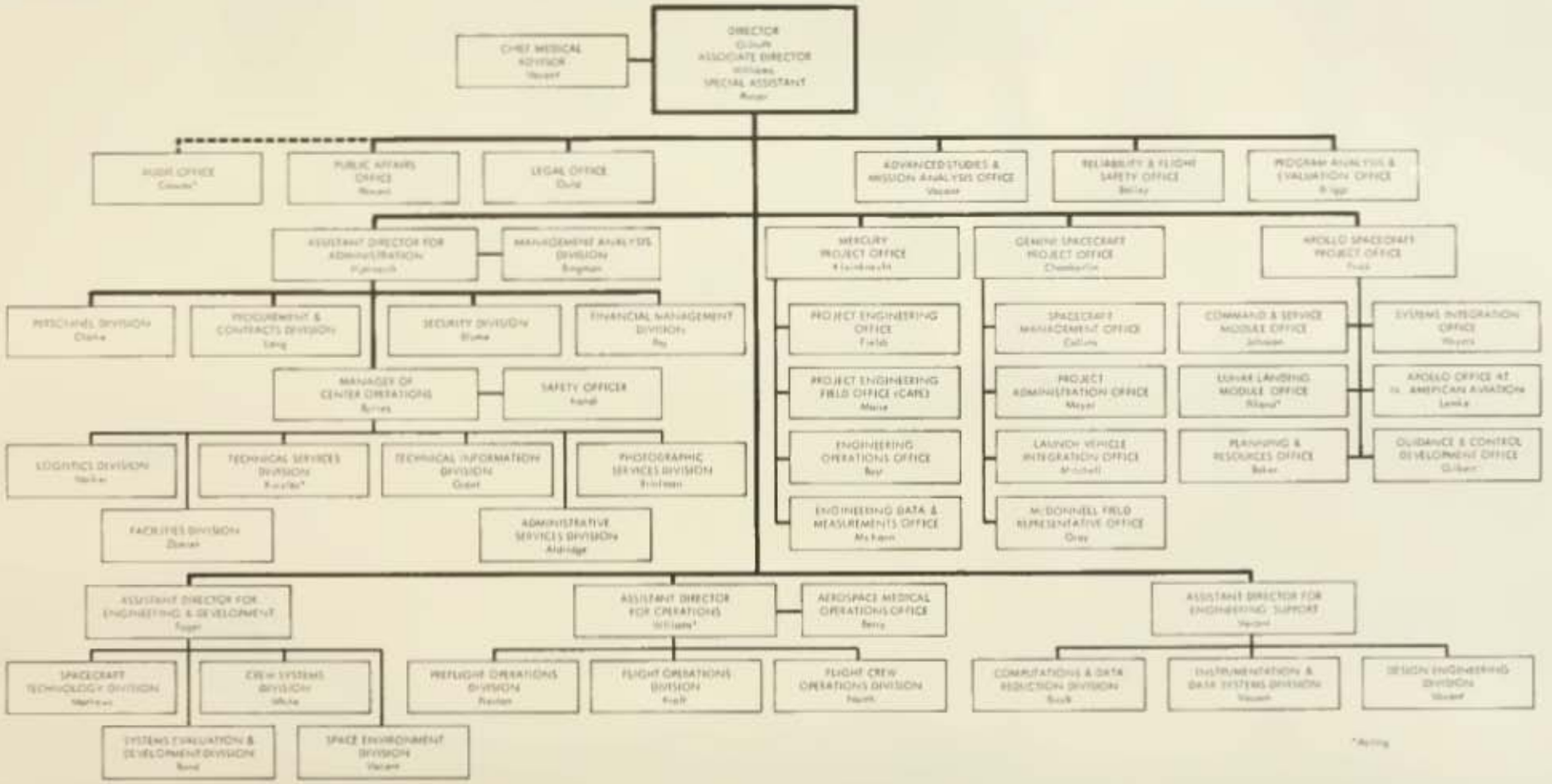
# APPENDIX C

## SPACE TASK GROUP
## September 26, 1960

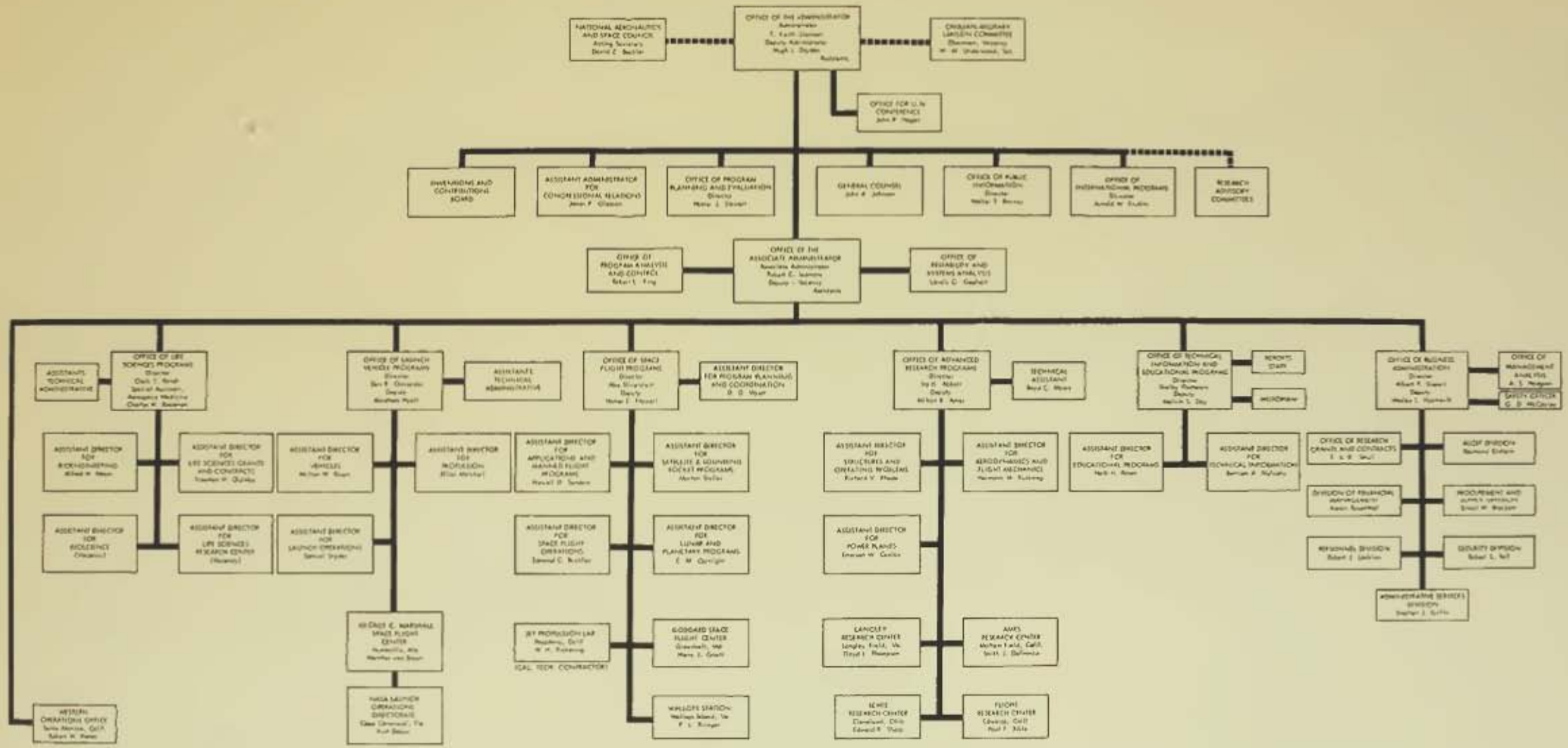


## MANNED SPACECRAFT CENTER

### September 1962

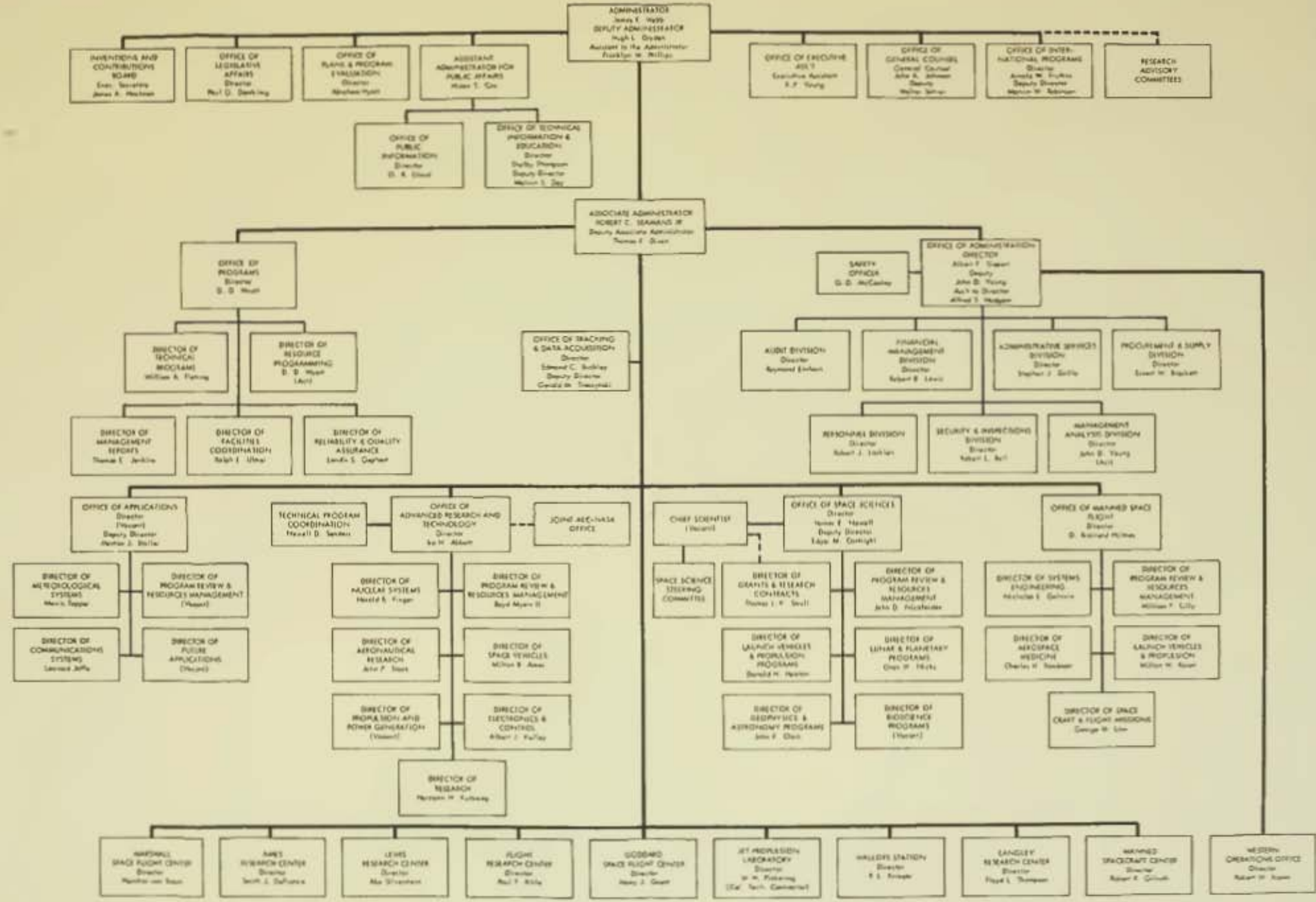


# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
## August 1960



# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

**November 1, 1961**



# Appendix D
# Flight Data Summary

# Flight Data Summary

The information in this revised flight data summary is taken from various sources according to the authors' best estimate of reliability. The basic format was made by Jack C. Heberlig for the NASA–MSC newspaper issue of "Mercury Program Summary," October 3–4, 1963, then republished as MSC Fact Sheet

| Mission | Pilot | Date | S/C No. | L/V No. | "Orig." scheduled in January 1959 | Orbits/period, min:sec | Weightless time, hr:min:sec |
|---|---|---|---|---|---|---|---|
| LJ-1 | ..... | 8/21/59 | BP | ..... | 7/59 | ..... | ..... |
| Big Joe | ..... | 9/ 9/59 | BP | 10-D | 8/59 | ..... | ..... |
| LJ-6 | ..... | 10/ 4/59 | BP | ..... | Insert | ..... | ..... |
| LJ-1A | ..... | 11/ 4/59 | BP | ..... | Insert | ..... | ..... |
| LJ-2 | "Sam" monkey | 12/ 4/59 | BP | ..... | 9/59 | ..... | 3:13 |
| LJ-1B | "Miss Sam" | 1/21/60 | BP | ..... | 11/59 | ..... | 0:28 |
| Beach abort | ..... | 5/ 9/60 | 1 | ..... | Insert | ..... | ..... |
| MA-1 | ..... | 7/29/60 | 4 | 50-D | 11/59 | ..... | ..... |
| LJ-5 | ..... | 11/ 8/60 | 3 | ..... | 12/59 | ..... | ..... |
| MR-1 | ..... | 11/21/60 | 2 | MR-1 | 10/59 | ..... | ..... |
| MR-1A | ..... | 12/19/60 | 2A | MR-3 | Insert | ..... | 5:30 |
| MR-2 | "Ham" chimp. | 1/31/61 | 5 | MR-2 | 12/59 | ..... | 6:40 |
| MA-2 | ..... | 2/21/61 | 6 | 67-D | 1/60 | ..... | ..... |
| LJ-5A | ..... | 3/18/61 | 14 | ..... | Insert | ..... | ..... |
| MR-BD | ..... | 3/24/61 | BP | MR-5 | Insert | ..... | ..... |
| MA-3 | Robot | 4/25/61 | 8 | 100-D | 2/60 | ..... | ..... |

No. 201 and in *Mercury Project Summary*, NASA SP–45, pages 50–51. But in expanding this chart, converting it to commonly understood units, and judging each mission's success or failure in the light of the overall program objectives, the authors have returned to the primary classified postlaunch memorandum reports for most of the figures herein.

The sixth column of the table shows the originally scheduled (January 1959) launch date. This early schedule represented optimistic planning in that it assumed a trouble-free preparation and flight program. As the program progressed, some flights were eliminated, others added, and objectives expanded, based on experience gained.

| Flight duration, hr:min:sec | Apogee/ perigee, st. miles | Range, max., st. miles | Velocity max.-spa., fix. mph | Max. q, psf | Max. g | Primary objective | Results SC/LV |
|---|---|---|---|---|---|---|---|
| 0:00:20 | 0.4 | 0.5 | ..... | ..... | ..... | Max. q abort and escape | F |
| 0:13:00 | 95 | 1,496 | 14,857 | 675 | 12 | Ablation heatshield | S/F |
| 0:05:10 | 37 | 79 | 3,075 | 3,400 | 5.9 | Capsule aerodynamics and integrity | P |
| 0:08:11 | 9 | 11 | 2,022 | 168 | 16.9 | Max. q abort and escape | P |
| 0:11:06 | 53 | 194 | 4,466 | 2,150 | 14.8 | Primate escape at high altitude | S |
| 0:08:35 | 9 | 12 | 2,022 | 1,070 | 4.5 | Max. q abort and escape | S |
| 0:01:16 | .5 | 1 | 976 | ..... | ..... | Off-the-pad escape | S |
| 0:03:18 | 8.1 | 6 | 1,701 | ..... | ..... | Qualify S/C—Atlas combination | F |
| 0:02:22 | 10.1 | 14 | 1,785 | 1,420 | 6 | Qualify MAC S/C at max. q | F |
| 0:00:02 | 0 | ..... | ..... | ..... | ..... | Qualify S/C—Redstone combination | F |
| 0:15:45 | 130.7 | 235 | 4,909 | 560 | 12.4 | Qualify systems for suborbital | S |
| 0:16:39 | 157 | 422 | 5,857 | 575 | 14.7 | Primate suborbital and auto abort | S/P |
| 0:17:56 | 114 | 1,432 | 13,227 | 991 | 15.9 | Qualify MA interface | S |
| 0:23:48 | 7.7 | 18 | 1,783 | 1,580 | 8 | Max. q escape and impact | P |
| 0:08:23 | 113.5 | 307 | 5,123 | 580 | 11 | Perfect MR booster | S |
| 0:07:19 | 4.5 | 0 | 1,177 | 880 | 11 | Quick test of S/C—Atlas orbit | F |

| Mission | Pilot | Date | S/C No. | L/V No. | "Orig." schedules in January 1959 | Orbits/period, min:sec. | Weightless time, hr:min:sec. |
|---|---|---|---|---|---|---|---|
| LJ-5B | ..... | 4/28/61 | 14A | ..... | Insert | ..... | ..... |
| MR-3 | Shepard: *Freedom 7* | 5/ 5/61 | 7 | MR-7 | 1/60 | ..... | 5:16 |
| MR-4 | Grissom: *Liberty Bell 7* | 7/21/61 | 11 | MR-8 | 2/60 | ..... | 5:18 |
| MA-4 | Robot | 9/13/61 | 8A | 88-D | 3/60 | 1/88:19 | 1:32:28 |
| MS-1 | ..... | 11/ 1/61 | NA | ..... | Insert | ..... | ..... |
| MA-5 | "Enos" chimp | 11/29/61 | 9 | 93-D | 3/60 | 2/88:26 | 3:04:38 |
| MA-6 | Glenn: *Friendship 7* | 2/20/62 | 13 | 109-D | 4/60 | 3/88:29 | 4:48:27 |
| MA-7 | Carpenter: *Aurora 7* | 5/24/62 | 18 | 107-D | 5/60 | 3/88:32 | 4:39:32 |
| MA-8 | Schirra: *Sigma 7* | 10/ 3/62 | 16 | 113-D | 6/60 | 6/88:55 | 8:56:22 |
| MA-9 | Cooper: *Faith 7* | 5/15/63 | 20 | 130-D | 8/60 | 22. 5/88:45 | 34:03:30 |

LJ = Little Joe
MA = Mercury-Atlas
MR = Mercury-Redstone
MS = Mercury-Scout

Beach Abort = Capsule escape rocket test
Big Joe = MA development flight
MR-BD = MR booster development

# APPENDIX D

| Flight duration, hr: min: sec | Apogee/ perigee, st. miles | Range, max., st. miles | Velocity max.-spa., fix. mph | Max. q, psf | Max. g | Primary objective | Results SC/LV |
|---|---|---|---|---|---|---|---|
| 0:05:25 | 2.8 | 9 | 1,780 | 1,920 | 10 | Max. q escape and sequence | S/P |
| 0:15:28 | 116.5 | 303 | 5,134 | 580 | 11 | Evaluate man-in-space | S |
| 0:15:37 | 118.3 | 302 | 5,168 | 610 | 11.1 | Corroborate man-in-space | P/S |
| 1:49:20 | 142.1/98.9 | 26,047 | 17,526 | 975 | 7.7 | S/C environmental control in orbit | P |
| 0:00:43 | ..... | ..... | ..... | ..... | ..... | ..... | F |
| 3:20:59 | 147.4/99.5 | 50,892 | 17,530 | 1,012 | 7.7 | Primate test of ECS in orbit | P/S |
| 4:55:23 | 162.2/100 | 75,679 | 17,544 | 982 | 7.7 | Evaluate man-in-orbit | S |
| 4:56:05 | 166.8/99.9 | 76,021 | 17,549 | 967 | 7.8 | Corroborate man-in-orbit | S |
| 9:13:11 | 175.8/100 | 143,983 | 17,558 | 964 | 8.1 | Man-machine in orbit for 9 hours | S |
| 34:19:49 | 165.9/100.3 | 546,167 | 17,547 | 974 | 7.6 | Manned 1-day mission in orbit | S |

S = Success
P = Partial
F = Failure

# Appendix E
# Personnel Growth

| Date | Scientists and engineers [a] | Total |
|---|---|---|
| October 1958 | 35 | 45 |
| December 1958 | (175) | 200 |
| June 1959 | (225) | (370) |
| December 1959 | 266 | 508 |
| June 1960 | (300) | (580) |
| December 1960 | 329 | 668 |
| June 1961 | 354 | 794 |
| December 1961 | 470 | 1152 |
| June 1962 | 799 | 1786 |
| December 1962 | 1254 | 2392 |
| June 1963 | 1514 | 3345 |

[a] Based on figures supplied by Mary K. Wood of NASA Headquarters Manpower Analysis Division.
( ) Interpolated figures.

| Date | Mercury Program (NASA personnel) [a] |
|---|---|
| *Space Task Group:* | |
| January 1959 | 150 |
| July 1959 | 350 |
| January 1960 | 500 |
| July 1960 | 550 |
| January 1961 | 680 |
| July 1961 | 770 |
| *Manned Spacecraft Center:* | |
| January 1962 | 850 |
| July 1962 | 670 |
| January 1963 | 500 |
| July 1963 | 400 |

[a] Based on figures supplied by Robert B. Merrifield of NASA-MSC Office of Long-Range Planning.

# Appendix F
# Project Mercury Cost Summaries

Precise costs directly attributable to any research and development program are very difficult to determine, and Project Mercury is no exception in this regard. Overhead and support costs accrued for several projects must be allocated and thus estimates rather than specifics are required. The total summary costs are official agency estimates as of February 28, 1966. Costs within the spacecraft manufacturer's contract are broken down in a second table, and a third details costs incurred by the Department of Defense in support of Project Mercury.

*Summary Estimates of Costs*

*Project Mercury*

[As of Feb. 28, 1966]

| | |
|---|---|
| *Mercury/1-Day Mission Projects:* | |
| Spacecraft | $143,413,000 |
| Launch vehicle procurement | 82,847,000 |
| Operations and support | 49,298,000 |
| Total project costs | $275,558,000 |
| *Tracking and Data Acquisition:* | |
| Operations and equipment | $71,900,000 |
| Facilities | 53,200,000 |
| Total TDA costs | $125,100,000 |
| Grand total costs | $400,658,000 |

## *Contract NAS 5–59 With McDonnell Aircraft Corp.*

## *Mercury Cost Breakdown*

[As of Oct. 14, 1965]

| | |
|---|---|
| Structure and Systems: | |
| Nonrecurring development | $40, 219, 000 |
| Recurring cost (20 units) | 49, 354, 000 |
| Models and mockups | 1, 489, 000 |
| Ground-test program | 887, 000 |
| Trainers | 3, 088, 000 |
| Thermal balance test program | 5, 712, 000 |
| Publications, specifications, and data | 345, 000 |
| Launch support: | |
| St. Louis | 1, 187, 000 |
| Cape Kennedy | 14, 750, 000 |
| Spare parts | 5, 432, 000 |
| Aerospace ground equipment | 9, 951, 000 |
| Repairs and modification | 1, 049, 000 |
| 1-day mission changes | 9, 337, 000 |
| Total | $142, 800, 000 |

## *Summary of DOD Support of Project Mercury*

[through June 1963]

[Extracted from: "Final Report to the Secretary of Defense on Department of Defense Support of Project Mercury," approved by Maj. Gen. L. I. Davis, USAF, Sept. 11, 1963]

| Agency | Type/level of support [a] | Actual costs (in thousand dollars) | | |
|---|---|---|---|---|
| | | NASA reimbursed | DOD absorbed | Total |
| *AIR FORCE:* | | | | |
| Space Systems Division (SSD). | Atlas boosters, launch crews and facilities, engineering, aircraft support. 23 people plus contractors. 216 aircraft-hours. | 73, 862 | 1, 351 | 75, 213 |
| AF Missile Test Center (AFMTC). | Operation of 3 network stations, launch support, assist in recovery. 173 people, 2,722 aircraft-hours. | 6, 569 | 5, 652 | 12, 221 |

[a] Average number of full-time people.

*Summary of DOD Support of Project Mercury*—Continued
(through June 1963)

| Agency | Type/level of support [a] | Actual costs (in thousand dollars) | | |
|---|---|---|---|---|
| | | NASA reimbursed | DOD absorbed | Total |
| Air Proving Ground Center (APGC). | Operation of 1 network station, assist in network training. 21 people, 551 aircraft-hours. | 22 | 956 | 978 |
| Air Force Communications Service (AFCS). | Communications engineering and installation; communicator deployment to contingency cites. 8 people. | 140 | 201 | 341 |
| Military Air Transport Service (MATS). | Airlift people and cargo. | 1,040 | 69 | 1,109 |
| Air Rescue Service (ARS). | Aircraft support to theater commanders; deploy forces for contingency recovery. 6,426 aircraft-hours. | 1,063 | 260 | 1,323 |
| Aeronautical Chart and Information Center (ACIC). | Cartographic Service. 10 people. | 5 | 190 | 195 |
| Tactical Air Command (TAC). | Aircraft support for contingency recovery. 546 aircraft-hours. | 42 | 87 | 129 |
| Air Defense Command (ADC). | Radar aircraft support. 245 aircraft-hours. | 3 | 271 | 274 |
| U.S. Air Force Europe (USAFE). | Deployment to remote sites for contingency recovery. 2,091 aircraft-hours. | 720 | 279 | 999 |
| Pacific Air Force (PACAF). | Deployment to remote sites for contingency recovery. 331 aircraft-hours. | 362 | 189 | 551 |
| Other. | Air Weather Service: weather surveillance and forecasting. AEDC and AFFTC: test facilities. | 8 | 911 | 919 |
| Total Air Force costs. | | 83,836 | 10,416 | 94,252 |
| *NAVY:* | | | | |
| Fleet Operations. | Astronaut and capsule recovery in planned areas. 1,441 ship-days, 4,044 aircraft-hours. | 8,934 | 15,110 | 24,044 |
| Pacific Missile Range (PMR). | Operation of 3 network stations; aircraft and tracking ship support. 144 people, 347 aircraft-hours, 170 ship-days. | 3,321 | 4,720 | 8,041 |
| Total Navy costs. | | 12,255 | 19,830 | 32,085 |

*Summary of DOD Support of Project Mercury*—Continued
(through June 1963)

| Agency | Type/level of support * | Actual costs (in thousand dollars) | | |
|---|---|---|---|---|
| | | NASA reimbursed | DOD absorbed | Total |
| *ARMY:* | | | | |
| White Sands Missile Range (WSMR). | Operate 2 network stations, 39 people. | 962 | 247 | 1, 209 |
| U.S. Army Europe (USAREUR). | Helicopter and pararescuemen support for contingency recovery. 107 Helo-hours. | 117 | 78 | 195 |
| Other. | LARC support, communications, test facilities, tracking-ship support. | 1, 221 | 405 | 1, 626 |
| Total Army costs. | | 2, 300 | 730 | 3, 030 |
| *BIOASTRONAUTICS (Army, Navy, Air Force):* | | | | |
| Operational. | Aeromedical monitors, recovery medical specialists, medical supplies, hospitals. 159 people average per mission. | 497 | 1, 070 | 1, 567 |
| Research and development. | Astronaut selection and training; laboratories. | 981 | 1, 320 | 2, 301 |
| Total bioastronautic costs. | | 1, 478 | 2, 390 | 3, 868 |
| Air Force | | 83, 836 | 10, 416 | 94, 252 |
| Navy | | 12, 255 | 19, 830 | 32, 085 |
| Army | | 2, 300 | 730 | 3, 030 |
| Bioastronautics | | 1, 478 | 2, 390 | 3, 868 |
| Total. | | 99, 869 | 33, 366 | 133, 235 |

# Appendix G: Project Mercury Tracking Net






MUC - Muchea, Australia
WOM - Woomera, Australia
CTN - Canton Island
HAW - Kauai Island, Hawaii
CAL - Point Arguello, Cal.
GYM - Guaymas, Mexico

WHS - White Sands, N. Mex.
TEX - Corpus Christi, Tex.
EGL - Eglin AFB, Fla.
CNV - Cape Canaveral, Fla.
BDA - Bermuda
ATS - Atlantic Ship

CYI - Grand Canary Island
KNO - Kano, Nigeria
ZZB - Zanzibar
CSQ - Coastal Sentry Quebec

*Ground Instrumentation Plan for Project Mercury*

[For 3-orbit missions]

| Station name | Coverage, passes | Radar | | Telemetry reception | Communication (capsule) | Command control | Acquisition | | | Ground communications | | | Timing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | C | | | | FA | SA | M | Voice | TTY | SSB radio | |
| Canaveral | 1, 2, 3 | (X) | X | X | X | X | X | (X) | ..... | X | X | ..... | X |
| Grand Bahama | 1, 2, 3 | ..... | (X) | X | X | ..... | ..... | ..... | X | X | X | ..... | AMR |
| Grand Turk | 1, 2, 3 | ..... | ..... | X | X | ..... | ..... | ..... | X | X | X | ..... | AMR |
| Bermuda | 1, 2, 3 | X | X | X | X | X | X | ..... | ..... | X | X | ..... | X |
| Atlantic ship | 1, 2, 3 | ..... | ..... | X | X | ..... | X | ..... | ..... | ..... | X | X | X |
| Grand Canary Island | 1, 2 | X | ..... | X | X | ..... | X | ..... | ..... | ..... | X | X | X |
| Kano, Nigeria | 1, 2 | ..... | ..... | X | X | ..... | ..... | X | ..... | ..... | X | X | X |
| Zanzibar | 1, 2 | ..... | ..... | X | X | ..... | ..... | X | ..... | ..... | X | X | X |
| Indian Ocean ship | 1, 2, 3 | ..... | ..... | X | X | ..... | X | ..... | ..... | ..... | X | X | X |
| Muchea, Australia | 1, 2, 3 | X | ..... | X | X | X | X | ..... | ..... | ..... | X | X | X |
| Woomera, Australia | 1, 2 | ..... | X | X | X | ..... | X | ..... | ..... | X | X | ..... | X |
| Canton Island | 1, 2 | ..... | ..... | X | X | ..... | ..... | X | ..... | ..... | X | ..... | X |
| Kauai Island, Hawaii | 2, 3 | X | X | X | X | X | X | ..... | ..... | X | X | ..... | X |
| Point Arguello, Calif | 2, 3 | X | X | X | X | X | X | ..... | ..... | X | X | ..... | X |
| Guaymas, Mexico | 1, 2, 3 | X | ..... | X | X | X | X | ..... | ..... | X | X | ..... | X |
| White Sands, N. Mex | 1, 2, 3 | ..... | X | ..... | ..... | ..... | X | ..... | ..... | X | X | ..... | X |
| Corpus Christi, Tex | 1, 2, 3 | X | ..... | X | X | ..... | X | ..... | ..... | X | X | ..... | X |
| Eglin, Fla | 1, 2, 3 | (*) | X | ..... | ..... | ..... | X | ..... | ..... | X | X | ..... | X |
| Goddard SFC | Ground communications | | | | | | | | | | | | |

FA = Fully automatic.
M = Manual.
*MPQ—31.
SA = Semiautomatic.
SSB = Single side band.
TTY = Telemetry.

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HUNTSVILLE, ALABAMA

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# THE MERCURY-REDSTONE PROJECT

December 1964

SATURN/APOLLO SYSTEMS OFFICE
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

# FOREWORD

The purpose of this report was to collect, into a single volume, a concise but complete history of the development program for the United States' first manned launch vehicle and to identify the significance of this program for the design and operation of future manned launch vehicles.

The report was prepared by the Apollo Support Department of the General Electric Company for the SATURN/Apollo Systems Office of the George C. Marshall Space Flight Center, NASA, Huntsville, Alabama. The information contained in the report has been obtained from reviews of a large number of project reports, which are included in the Bibliography, and personal interviews with technical personnel who were part of the MERCURY-REDSTONE team. Some of the major contributors to the MERCURY-REDSTONE launch vehicle were the Army Ballistic Missile Agency, the Marshall Space Flight Center and Space Task Group (both of NASA), Chrysler Corporation and the Rocketdyne Division of North American Aviation, Inc.

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# SECTION 1

# SUMMARY

## 1.1 GENERAL

This report presents a brief but complete development history of the MERCURY-REDSTONE Project - the United States' first manned launch vehicle. At this time, approximately three years after the last flight of the vehicle, the MERCURY-REDSTONE Project has a continuing significance for manned launch vehicles in that it developed solutions to problems which are still applicable to the systems presently in use or those planned for later development. Such questions as the following must still be answered for each new manned system:

- When is a vehicle ready for manned flight?
- How do we save the astronaut in the event of a failure?
- How do we instill an awareness of the significance of their efforts on reliability and safety to each individual involved in the program?
- How do we provide for ground personnel safety in the event of a failure?
- How do we coordinate and technically integrate the efforts of widely dispersed engineering groups with differing points of view ?

The answers provided by MERCURY-REDSTONE to these questions are described in this report. The lessons to be learned from the failures as well as the success of the project are identified and summarized. In addition, special developments in the program are presented such as the first extensive investigation and test of a booster recovery system.

Section 9 summarizes the major contributions of the MERCURY-REDSTONE Project to manned launch vehicles in the areas of man-rating, design, testing, and operations. In addition, specific equipments were developed which are still applicable for current manned launch vehicle programs. These include the following:

- Emergency egress operations with a mobile aerial tower and an armored emergency rescue vehicle.
- Abort impact predictor for premature mission termination.
- "White Room" enclosing the spacecraft within the launch pad service structure.
- Automatic Inflight abort sensing system.

- Range safety destruct procedures and implementation.
- Prelaunch weather survey techniques.

Other sections of this report present descriptions of the mission, the vehicle design, the man-rating program, development testing, checkout and launch operations, flight testing, and a reference. As a prelude to an orbital flight program, the MERCURY-REDSTONE missions provided an opportunity to check out and evaluate the following:

- Spacecraft systems design.
- Reactions of an astronaut subjected to brief periods of space flight (weightlessness and booster accelerations).
- Launch and recovery operations.
- Manned flights less hazardous than orbital flights.

Suborbital flights provided an excellent simulation of the accelerations imposed on a capsule during its return from orbit even though their duration was not as great.

The mission objectives for the MERCURY-REDSTONE launch vehicle were as follows:

- Familiarize man with a brief but complete space flight experience including:
  a. Liftoff.
  b. Powered flight.
  c. Weightless flight (for a period of approximately 5 minutes).
  d. Re-entry.
  e. Landing.
- Evaluate man's ability to perform as a functional unit during space flight by:
  a. Demonstrating manual control of capsule attitude before, during, and after retrofire.
  b. Use of voice communications during flight.
- Study man's physiological reactions during space flight.
- Recover the astronaut and capsule.

The adaptation of the tactical missile was made in a series of design changes and modifications based on ground and flight tests. The guideline for conversion of the REDSTONE design and operations to a manned payload were:

- Safety.
- Acceptable human factors.
- No marginal performance.

The implementation of the above guidelines was carried out in three major phases:

- Basic Redesign.
- Modification after Ground Tests.
- Modification after Flight Tests.

## 1.2 BASIC REDESIGN

A basic redesign was necessary to adapt the REDSTONE to the MERCURY mission. The required modifications and additions made the new launch vehicle physically distinguishable from both the REDSTONE and JUPITER-C as shown in Figure 1-1. To carry out the basic redesign program, the following major areas were considered:

- Increased Performance: Elongation of the REDSTONE propellant tanks, increasing nominal engine burning time from 123.5 to 143.5 seconds.
- Simplicity: Consisted of three major changes:
  a. Installed simple control system (LEV-3 autopilot), eliminated stabilized platform (ST-80).
  b. Installed new pressurized instrumentation compartment.
  c. No separation between aft unit and container section.
- Crew Safety: Addition of an automatic inflight abort sensing system to the booster and emergency egress operations were incorporated at the launch site. Utilization of alcohol as a fuel in lieu of the more toxic Hydine used in JUPITER-C. These were the major provisions in man-rating and are covered in greater detail later in the report.

In all, a total of over 800 changes were made before the MERCURY-REDSTONE Project was completed. The major changes listed above plus many minor changes increased the booster's reliability to the extent that astronaut abort was never necessary.

## 1.3 MODIFICATION AFTER GROUND TESTS

During the vibration test program, several components failed or were damaged. These included:

- An engine piping elbow.
- An $H_2O_2$ bottle bracket.
- The abort rate switch mounting bracket.
- Wires in the roll rate switch.
- An antenna mounting stud.

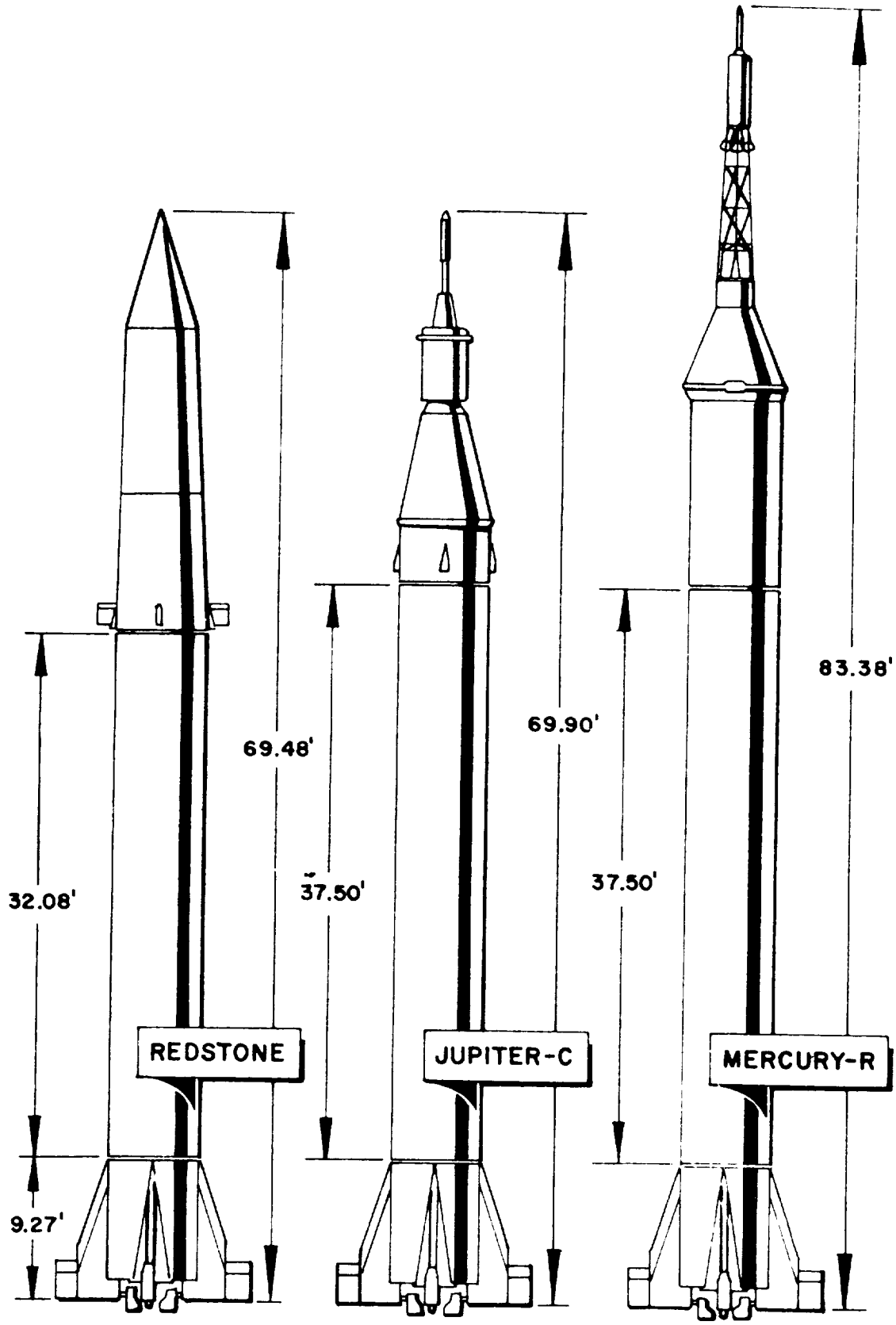



Figure 1-1. The REDSTONE, JUPITER-C, and MERCURY-REDSTONE Launch Vehicles

Similar problems occurred in other components. The success of the modifications proved the value of total system testing. Since the A-7 engine was new, extensive test firings were made. During these firings, combustion instability was discovered to occur at 500 cps. Enlarging the injector holes proved to be the solution. Tracking down the source of another low frequency oscillation eventually led to a study of the static test tower. Modification of the test tower removed this trouble.

## 1.4 MODIFICATION AFTER FLIGHT TESTS

Problem areas discovered during the flight test program led to the following modifications:

- MR-1 launch attempt proved the need for ground-negative until all other electrical connections were separated. Thus, a one foot ground strap was added.
- A scale factor error due to excessive pivot torque on the LEV-3 longitudinal integrating accelerometer caused MR-1A to experience an excess cutoff velocity of 80 meters per second. Use of softer wire and relocation of five of eight electrical leads solved the problem.
- As a backup to the integrating accelerometer fix, a time-based engine cutoff at 143 seconds was employed on MR-2 and MR-BD. These later flights proved the accelerometer functioned properly, thus use of the cutoff timer was discontinued.
- The thrust controller on MR-2 failed wide-open causing LOX depletion 0.5 second before deactivation of the abort $P_c$ switches. To prevent a similar occurrence on the remaining flights, velocity cutoff arming and switching of the $P_c$ switches to the depletion mode (fuel depletion arming) were separated. Velocity cutoff arming was advanced to 131 seconds to take care of earlier than predicted cutoff velocity, while fuel depletion arming was set at 135 seconds, keeping the combustion chamber pressure abort capability as long as possible, but removing this capability early enough to take care of a high propellant consumption rate.
- Flights MR-1A, MR-2, and MR-BD experienced roll rates approximately twice that of REDSTONE (8 vs 4 degrees per second); however, since the vehicle was not subject to damage at this rate, the roll rate abort sensor was deleted after MR-BD. The roll angle abort limit of 10 degrees was retained.
- An interaction of the second bending mode with the yaw and pitch axis control required the addition of a network filter to reduce control loop gain between 6 and 10 cps. The interaction was noted on flights MR-1A and MR-2.

- Flights MR-1A, MR-2, and MR-BD indicated excessive adapter section vibrations. On MR-3 these were dampened with 340 pounds of a lead impregnated rubber compound added to the bulkhead and walls of the section. Fourteen longitudinal stiffeners were also added to the internal skin surface. Since Astronaut Shepard still noted considerable vibrations during boost on MR-3, an additional 102 pounds of the dampening compound, X-306, were added to the instrument conpartment of MR-4

## 1.5 FLIGHT PROGRAM REVIEW

The MERCURY-REDSTONE Program was originally scheduled for eight flight tests. Only six of the planned flights were attempted, as the success of the program warranted the cancellation of the last two planned flights. Succeeding flights came at intervals of about two months; the interval from the first launch attempt to Astronaut Grissom's flight, covering only nine months (21 November 1960 to 21 July 1961). During this relatively short period the capability of placing man in space was proved and the path charted to full orbital flight. Only the first two MERCURY-REDSTONE flights were originally intended to be unmanned; however, failures caused this number to be increased to four before the two manned flights took place.

The final MERCURY-REDSTONE Program included the following flights: Four developmental (MR-1, MR-1A, MR-2, and MR-BD), and two manned operational (MR-3 and MR-4).

## 1.6 MR-1 MISSION

The first MERCURY-REDSTONE flight vehicle, MR-1, was launched on 21 November 1960, at 0859 hours EST, at Cape Canaveral (now Cape Kennedy). Its primary mission was to qualify the automatic inflight abort sensing system and the Spacecraft-launch vehicle combination for the MERCURY ballistic mission. The mission included obtaining a velocity of Mach 6.0 during powered boost and successful separation of the spacecraft. After ignition and mainstage only a short vehicle motion occurred. Investigation revealed that a "sneak circuit" through the control plug and ground network gave a premature booster cutoff. The booster settled back vertically on its launch stand after having risen only 3.8 inches. The booster was subsequently deactivated.

As a result of extensive tests, the following changes were incorporated:

- A followup electrical ground line was provided to eliminate the "sneak circuit."

- An "engine pressure switch-missile program device permission circuit" was incorporated to insure reaction to an authentic cutoff signal just prior to 135 seconds after liftoff.

## 1.7 MR-1A MISSION

Due to problems encountered with MR-1, the second MERCURY-REDSTONE launch was to repeat the first mission, hence its designation MR-1A. The launch occurred at 1115 EST on 19 December 1960. The successful launch of MR-1A was slightly compromised by a malfunction in the integrating gyro, causing cutoff velocity to be higher than normal. This higher velocity caused the capsule to experience maximum re-entry deceleration. A higher than expected mixture ratio was experienced, but a safe margin of propellant remained. Separation rate between the capsule and booster was greater than the value predicted because of the "popgun effect." MR-1A completed its mission with the abort system functioning as expected. All measured abort parameters remained below the maximum tolerable levels.

## 1.8 MR-2 MISSION

MERCURY-REDSTONE MR-2 was launched on 31 January 1961, at 1145 EST. In the six weeks between the second and third launches, several changes were made. A malfunction of the chamber pressure controller on MR-2 caused the engine to operate at a higher thrust level than expected. This malfunction was the direct cause of the following factors:

- The higher thrust level resulted in a LOX depletion before the normal cutoff circuit was armed.
- When the chamber pressure decayed, an abort signal occurred.
- An additional impulse was given the capsule by the firing of the escape rocket.
- Because the retro rockets did not fire in the abort mode, the capsule experienced high deceleration during re-entry.

These factors combined to cause the capsule to impact beyond the target area. During the first two flights (MR-1 and MR-1A), Range Safety noted that the REDSTONE's steep trajectory caused the missile to remain over land too long for safety, and that the azimuth of 105 degrees was very close to the right-hand impact limit line established by the range.

## 1.9 MR-BD (BOOSTER DEVELOPMENT) MISSION

The booster development missile (MR-BD) was launched on 24 March 1961, at 1230 EST. The fourth MERCURY-REDSTONE evaluated changes incorporated in the booster after the MR-2 flight test that reduced vehicle oscillations and vibrations and which assured proper velocity cutoff. The second bending mode frequencies again appeared in the angular velocity measurements, but their amplitudes were only one-half of those experienced in the MR-2 flight test. This indicated that the control filter, dampening compound, and stiffeners in the adapter section were effective in reducing the amplitude of the oscillations. The integrating gyro gave cutoff at the proper velocity, indicating that the corrective measures were successful.

## 1.10 MERCURY-REDSTONE MR-3 MISSION

MERCURY-REDSTONE MR-3, was the first manned flight. With Astronaut Shepard aboard, MR-3 lifted off at 0934 EST on 5 May 1961. All missions assigned to the booster were successfully accomplished and no system malfunction occurred. No evidence of second bending mode feedback in the control system was noted. This further proved the effectiveness of the filter network incorporated after the MR-2 flight test. The astronaut reported buffeting during powered flight, but telemetry data indicated vibration levels were lower than those of the previous MERCURY-REDSTONE flights. However, to lower these vibrations, additional dampening material was added to the instrument compartment prior to the next flight.

## 1.11 MR-4 MISSION

Concluding the MERCURY-REDSTONE Program was MR-4 carrying Astronaut Grissom in the second successful manned suborbital flight. Again all systems worked properly and all mission objectives were achieved, excepting capsule recovery. As a result of the capsule escape hatch malfunction during recovery, water entered the capsule and increased its weight beyond the capacity of the recovery helicopter. Improved vibration data indicated that the additional dampening material added to the instrument compartment proved effective. The success of MR-4 on 21 July 1961, at 0720 hours, EST, ended the MERCURY-REDSTONE flight program. The first step of "man-into-space" had been accomplished.

A compilation of the milestones of the MERCURY-REDSTONE Project is presented below.

## 1.12 MILESTONES OF THE MERCURY-REDSTONE PROJECT

1958

| | |
|---|---|
| June | A Working Group was formed from personnel of the Langley Aeronautical Laboratory and the Lewis Propulsion Laboratory, NACA to consider a man-in-space program. |
| September | NACA and DOD's Army Research Projects Agency (ARPA) established a Joint Manned Satellite Panel to formulate the plans of the Working Group. |
| October | The plans of the Panel for a Manned Satellite Program were approved by the Director of ARPA and the Administrator of NASA (NACA became NASA on 1 October 1958). The joint working group and panel then became the Space Task Group and began operations at the Langley Research Center. |
| October 6 | NASA and the Army Ordnance Missile Command (AOMC) met, and AOMC tentatively agreed to supply 10 Redstone and 3 Jupiter missiles for the program. |
| November 3 | NASA informed AOMC to proceed with an 8 Redstone missile program. |
| November 26 | Project MERCURY was officially assigned to the manned-satellite program. |

1959

| | |
|---|---|
| January 8 | NASA funded AOMC for 8 Redstones. The Army Ballistic Missile Agency (ABMA), an element of AOMC, began production planning and scheduling of the MERCURY-REDSTONE Project. |
| April 27 | Project MERCURY was assigned a "DX Rating," the nation's highest priority rating. |

1960

| | |
|---|---|
| January 7 | The first MERCURY-REDSTONE booster MR-1 was static test fired at ABMA. |
| February | MR-1 completed its checkout and test program and was stored pending receipt of the first MERCURY capsule. |
| June 30 | Spacecraft No. 2, the first MERCURY capsule, arrived at ABMA for checkout and booster compatibility tests. |
| July 1 | The MERCURY-REDSTONE Project was officially transferred from ABMA to the Marshall Space Flight Center (MSFC) of NASA. |
| July 20 | MR-1 underwent a similar flight test at MSFC. |
| August 3 | MR-1 and Spacecraft 2 arrived at Cape Canaveral. |

| | |
|---|---|
| August 22 | Erection of MR-1 was completed. |
| September 26 | After storage to avoid a hurricane, MR-1 was re-erected and the capsule mated. |
| November 21 | After a third mating of the spacecraft, MR-1 failed during launch. A ground support cable connection caused premature shutdown. |
| December 19 | MR-1A was successfully launched, providing the first flight test of the MERCURY-REDSTONE. |

1961

| | |
|---|---|
| January 31 | Flight MR-2 (Booster MR-2 and Capsule 5) was successfully launched, carrying the 37-pound chimpanzee "Ham" into space. |
| February | The decision was made to make one additional booster development (BD) flight before attempting a manned flight. |
| March 24 | Flight MR-BD was a successful launch, proving the flight worthiness of the booster design improvements. This flight also provided testing of the emergency egress tower and other emergency rescue ground equipments. |
| May 5 | Flight MR-3 successfully carried Astronaut Shepard in the planned ballistic trajectory; he thus became the United States' first man in space. |
| July 21 | The second man in space, Astronaut Grissom, was successfully launched aboard Flight MR-4. |
| September | The MERCURY-REDSTONE Program was phased out. |

# SECTION 2

# INTRODUCTION

The development modification of the first launch vehicle suitable for a manned payload was accomplished in less than two years. During this brief time, the MERCURY-REDSTONE Project team encountered an entirely new scope of design problems in modifying an existing vehicle, the REDSTONE, for its manned payload. Rocket propulsion systems had previously been utilized in manned aircraft such as the German ME-163 and the American X-series of research vehicles (X-1, X-1A, X-2, and X-15); however, the relatively small quantity of propellant on these aircraft and their ability to maintain flight without propulsion indicated that the REDSTONE engineers would be required to resolve significant new problems including the following:

- High explosive yield of propellants.
- Acceleration, noise, and vibration environments.
- Safety for ground personnel and facilities.
- Water recovery of the payload.
- On-pad emergency egress of the astronaut.
- Abort sensing and implementation procedures.
- Abort parameter limits to maximize safety without jeopardizing mission reliability.

The short development time required and the success of the two manned flights (the fifth and sixth launches of the series) are an indication of the dedication and competence which was applied to this task. However, greater tribute to the project is the fact that many of the basic solutions developed in the modification of the REDSTONE for manned flight are valid for present and future launch vehicles (as evidenced by their use in the SATURN/APOLLO Program).

The purpose of this report, then, is to review the MERCURY-REDSTONE Project emphasizing the problems encountered, their resolutions and their implications and applicability to future manned launch vehicles. Often, the items of greatest technical importance which may be useful for succeeding programs is so dispersed among many technical reports that they are retained in a single location only in the memory of a few key project personnel. It is hoped that this report, which points out unique features of the MERCURY-REDSTONE Project, such as the recoverable booster tests as well as the failures and successes of the flight and ground test programs, will serve as a focal

point for guidance of future manned systems project engineers. More detailed information than could be included in this brief report can be obtained from the reports listed in the References, which served as sources for the information presented here.

By early 1959, the performance required of a launch vehicle needed for the first phase of the manned-flight program was determined. The vehicle had to have both the reliability and performance to place a manned, two-ton payload safely into a suborbital trajectory in which at least 5 minutes of weightlessness would be experienced and an apogee of at least 100 nautical miles would be attained. In addition, the vehicle had to be available in time to support the desired flight schedule. These requirements narrowed the choice to launch vehicles which had already been developed for a military mission. Section 3 of this report presents a discussion of the mission and launch vehicle selection.

The REDSTONE, a tactical surface-to-surface missile had been under development and testing for several years prior to its utilization in the MERCURY Program. The first launch of a REDSTONE missile took place on 20 August 1953, almost 8 years prior to the first manned MERCURY-REDSTONE launch on 5 May 1961. During this interim, the basic missile had undergone several development changes and improvements in its design and performance.

At the time of its selection in January 1959 for the MERCURY Program, two versions of the REDSTONE design existed. The first, an advanced model (Block II) of the tactical missile, utilized an improved engine, the A-7, and alcohol and LOX as propellants. The second, the JUPITER-C, was a multistage vehicle utilizing increased capacity tanks compared to the REDSTONE, the Model A-5 engine, and the more toxic Hydine (60 percent UDMH, 40 percent diethylene triamine) and LOX as propellants. This extended performance booster stage was coupled with upper stages of scaled Sergeant solid propellant motors. A four stage version of the JUPITER-C placed EXPLORER I, the free world's first satellite, into orbit.

Since the Block II REDSTONE, the most advanced and reliable version could not meet the MERCURY performance requirements, the configuration selected coupled the Model A-7 engine and propellants of the Block II model with the enlarged capacity tanks of the JUPITER-C. It is interesting to note that by the time of the first manned launch (MR-3), the total reliability of all 69 previous REDSTONE flights was 81 percent; however, the Block II model had achieved 11 consecutive successes and the JUPITER-C had achieved seven consecutive successes.

The REDSTONE, as modified above, satisfied the basic MERCURY Program requirements for the suborbital flight with regard to both performance and availability. However, even though the vehicle had demonstrated a high reliability, it did not incorporate safety features which would prevent the loss of an astronaut in the event of a mission failure. The modification of the vehicle design and launch operations and the development of new quality control and test procedures, necessary for its use as a manned payload carrier, constitute the major technical contributions of the MERCURY-REDSTONE Program to manned launch vehicles. This development, referred to as man-rating, had as its three major guidelines:

- Safety during launch.
- Satisfactory operation within human-factors tolerances.
- Adequate performance margins for mission reliability.

The actual adaption of the vehicle and its operations for manned flight took place in three phases and are treated separately in this report:

- Preliminary modification prior to application.
- Modifications after ground tests.
- Modifications after flight tests.

Although there were hardware changes during the development the basic man-rating program and design concepts did not require major alteration.

The MERCURY-REDSTONE mission was accomplished by the joint participation of the Marshall Space Flight Center (MSFC), then the Development Operations Division of the Army Ballistic Missile Agency (ABMA) with the Space Task Group (STG) of the National Aeronautics and Space Administration (NASA) in the MERCURY Program. Program management was directed by the Space Task Group. At ABMA the MERCURY-REDSTONE Project Office was established to aid in redesigning, modifying, and preparing the REDSTONE to meet the specific MERCURY mission objectives. Coordination panels were set up between McDonnell Aircraft Corporation (MAC), manufacturer of the capsule, and STG and MSFC to coordinate design changes between the three agencies involved in the program. The operation of these panels proved so successful in implementing design and operational integration that they are still the main agency for technical coordination used in the SATURN/APOLLO Program today.

SECTION 3

# MERCURY-REDSTONE MISSION

## 3.1 MISSION OBJECTIVES

By early 1959, several decisions were made in regard to the performance required of a launch vehicle needed for the first phase of the manned flight program. The vehicle had to have both the reliability and performance to place a manned, two-ton payload safely into a suborbital trajectory of 100 nautical miles apogee in which at least 5 minutes of weightlessness would be experienced. In addition, it would have to be available in time to support the desired flight schedule of the later orbital flights with the ATLAS booster. These requirements narrowed the choice to launch vehicles which had already been developed for a military mission.

At this time, two surplus JUPITER-C missiles were available from the Army Ballistic Missile Agency (ABMA). The JUPITER-C was an advanced version of the REDSTONE, a tactical military missile with a record of over 50 successful flights, verifying its reliability. The original REDSTONE could not meet the mission requirements; however, the JUPITER-C had elongated propellant tanks, a lighter structure, and the required performance for MERCURY. The JUPITER-C launch vehicle had been used for conducting re-entry studies and for placing the first United States satellite, EXPLORER I, into orbit.

Therefore, the REDSTONE vehicle, in its JUPITER-C modification, satisfied the basic MERCURY suborbital requirements of availability and performance. However, the JUPITER-C did not incorporate all the necessary safety features, and further adaptation was necessary for its use as a manned launch vehicle. This development, which is sometimes referred to as man-rating, had as its three major guidelines: safety during launch, satisfactory operation from a human-factors standpoint, and adequate performance margins.

To meet performance requirements, use of the elongated JUPITER-C tanks was necessary. These tanks gave the MERCURY-REDSTONE launch vehicle a nominal engine burning time of 143.5 seconds, 20 seconds more than the original REDSTONE vehicle. This greater burning time required the addition of a seventh high-pressure nitrogen

tank to pressurize the larger fuel tank and an auxiliary hydrogen peroxide tank to power the engine turbopump.

To decrease the complexity for the basic MERCURY-REDSTONE three changes were made:

- The REDSTONE stabilized platform (ST-80) was replaced by the LEV-3 autopilot for vehicle guidance. The LEV-3 system was less complex, more reliable, and met the guidance requirements of the MERCURY-REDSTONE mission.
- The aft unit, containing the pressurized instrument compartment and adapter were permanently attached to the center tank assembly. In the tactical version, this unit separated with the payload to provide terminal guidance.
- A short spacecraft adapter, including the spacecraft launch vehicle separation plane, was supplied by the spacecraft contractor. This arrangement simplified the interface coordination.

For the MERCURY-REDSTONE launch vehicle, alcohol was chosen as fuel. Although the JUPITER-C had used unsymmetrical diethyltriamine (UDETA) for greater performance, its toxicity was higher than that of alcohol and was considered to be undesirable for manned flights. However, the selection of alcohol led to a problem with the jet control vanes because the extended burning time caused greater erosion of these vanes. Hence, a program was initiated to select jet vanes of the highest quality for use in MERCURY.

To provide for maximum crew safety, an automatic inflight abort-sensing system was added to the launch vehicle and an emergency egress operation was established for the launch complex. These factors were primary considerations in man-rating the REDSTONE.

The MERCURY-REDSTONE was aerodynamically less stable than the standard REDSTONE. Because of the unique payload characteristics and the elongated tanks, the MERCURY-REDSTONE was expected to become unstable in the supersonic region approximately 88 seconds after liftoff. To compensate for this instability, 687 pounds of ballast were added forward of the instrument compartment.

Changes were also necessary because of the decreased lateral bending frequencies. The configuration and payload changes reduced the MERCURY-REDSTONE bending

frequencies to one-fourth those experienced by the standard REDSTONE. As a result, resonance problems appeared during both ground and flight testing, and the second bending mode had to be filtered out of the control system to prevent feedback.

## 3.2 FLIGHT TRAJECTORY

The trajectory for the MERCURY-REDSTONE mission was based on the performance predicted for the booster vehicle's modified propulsion system. Included in the calculations were the thrust available during all phases of flight including thrust buildup at launch after liftoff and during the final decay subsequent to engine shutdown. Longitudinal forces derived from the expected upper atmosphere winds were also included. All attitude references were made with respect to the launch vertical. Figures 3-1, 3-2, and 3-3 are typical curves for dynamic pressure, velocity, and acceleration versus time for the MERCURY-REDSTONE mission.

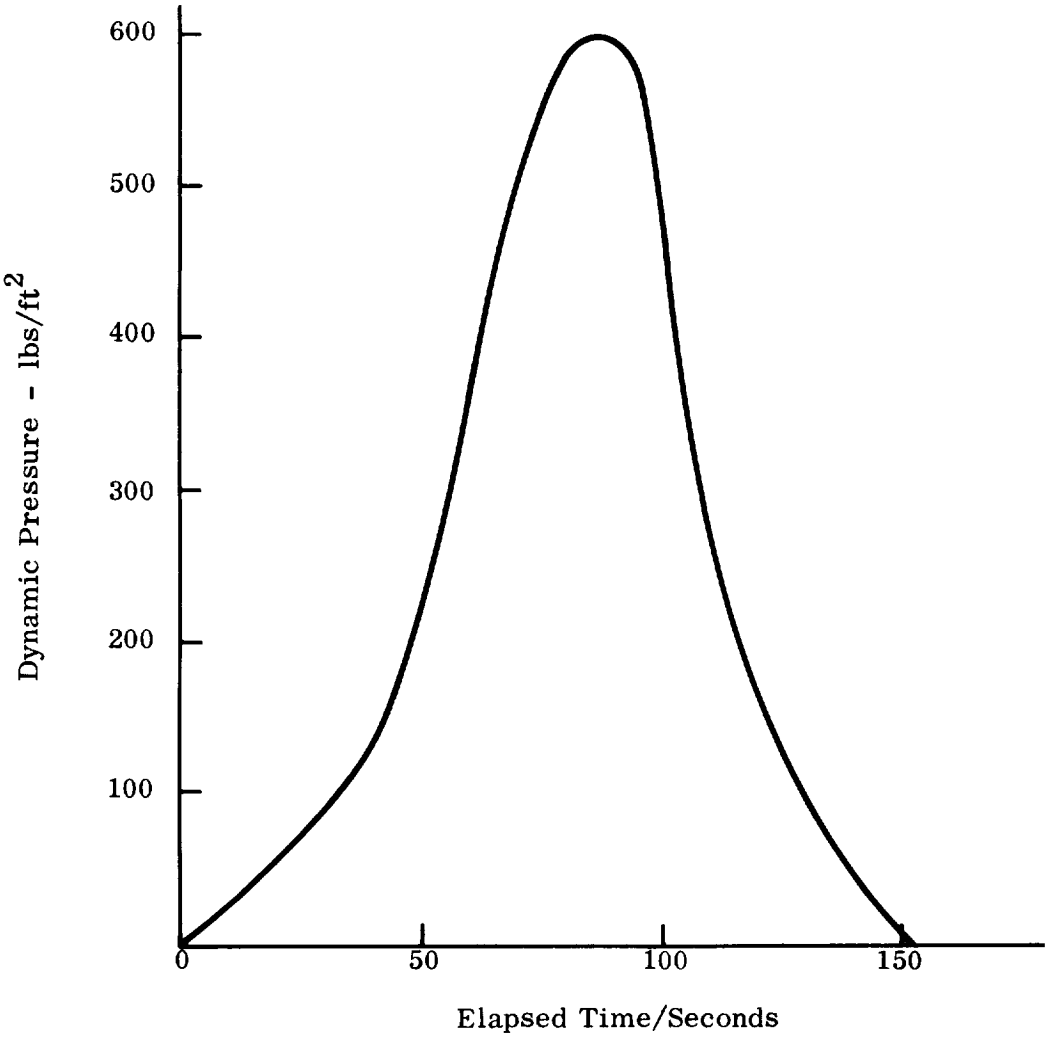



Figure 3-1. Dynamic Pressure During Boost, MR-4 Mission

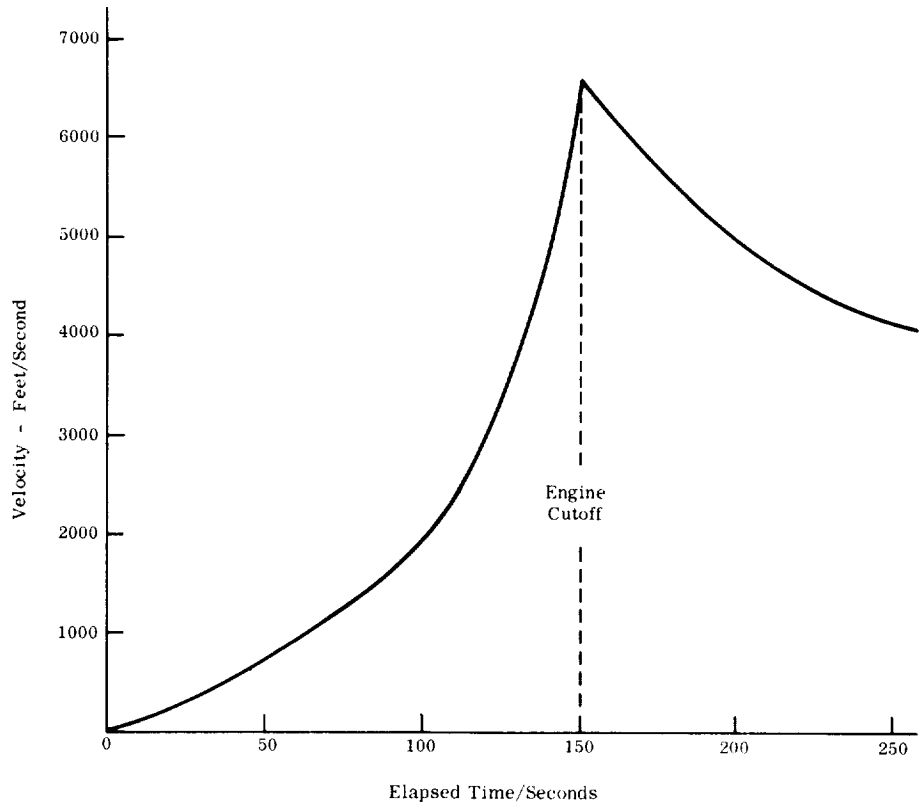



Figure 3-2. Velocity During Boost, MR-4 Mission

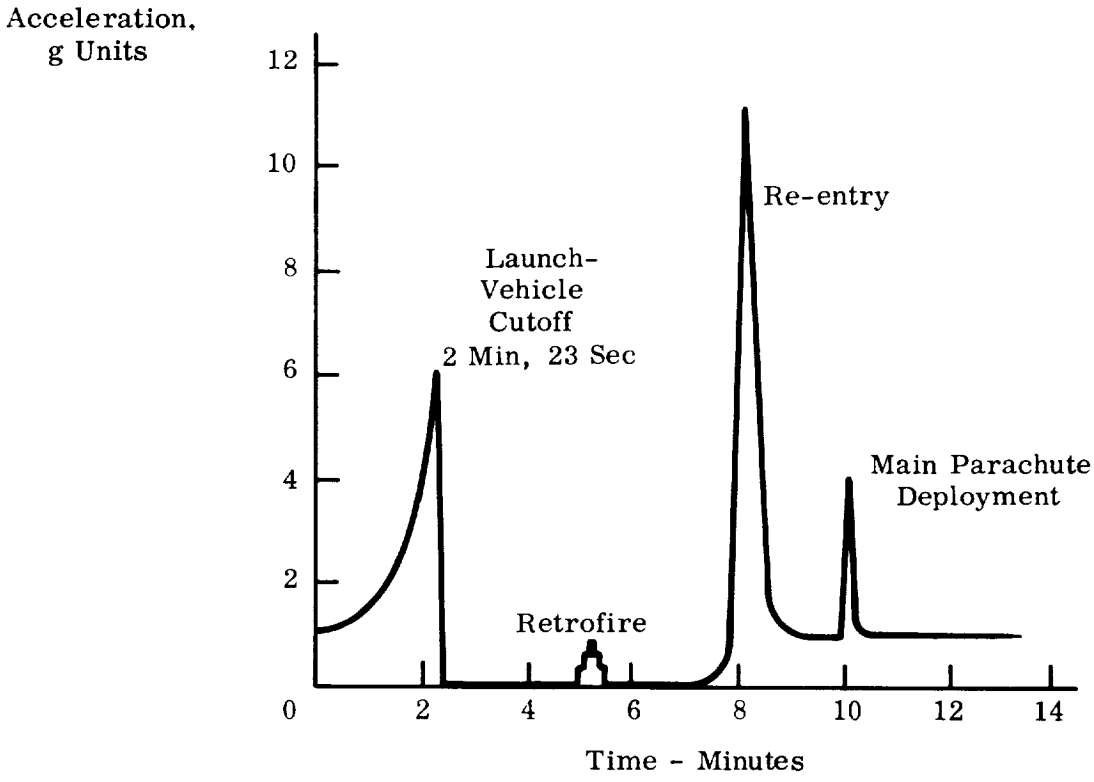



Figure 3-3. Axial Acceleration versus Time, MR-4 Mission

Many aerodynamic studies were undertaken to ascertain the normal loads on the vehicle which could have some immediate influence on the shaping of the trajectory of vehicle structural or control design. Other considerations were involved with trajectory shaping. These included the tilt program design with respect to the time over land in the Cape area.

The vehicle's flight path remained over the Cape area for the first thirty seconds following liftoff and presented a difficult situation for range safety. During this time, the abort system was not permitted to shut down the engine, thus reducing the probability of an early mission abort resulting in a hazardous condition for ground personnel and equipment.

Range safety considerations also played an important role in determining the specified trajectory limits. The original azimuth selection of the 105 degrees east of north was made from the standpoint that no other pads were along the flight path. This launch azimuth was later changed to 102 degrees after the MR-1A launch. The MR-4 mission was launched at 100 degrees azimuth. (See Section 8.)

## 3.3 MISSION PROFILE AND SEQUENCE OF EVENTS

The MERCURY-REDSTONE launch profile injected the MERCURY capsule in a suborbital flight at a nominal, earth-fixed velocity of 6500 feet per second. The injection angle was 41.80 degrees, cutoff altitude 200,000 feet, and Mach number 6.3. The maximum acceleration at engine cutoff was 6.3 g's.

In Table 3-1, several important booster sequencing points are indicated. Thirty seconds after liftoff a circuit was activated permitting automatic engine cutoff prior to abort. Prior to this time, only the range safety officer could initiate an engine shutdown. At 129.5 seconds the normal shutdown circuitry was armed. This prevented early jettisoning of the escape tower. At 131 seconds the velocity cutoff accelerometer was armed. This occurred twelve seconds before nominal cutoff to allow for higher than nominal performance or for off-nominal propellant mixture ratio and subsequent early propellant depletion. For the same reasons, the chamber pressure abort switches were deactivated at 135 seconds, thus preventing an abort at normal cutoff. Both cutoff activation and pressure switch deactivation were originally scheduled to occur at 137.5 seconds, but as a result of the early shutdown of MR-2, the indicated times were selected for all subsequent flights. Figure 3-4 shows a typical flight profile.

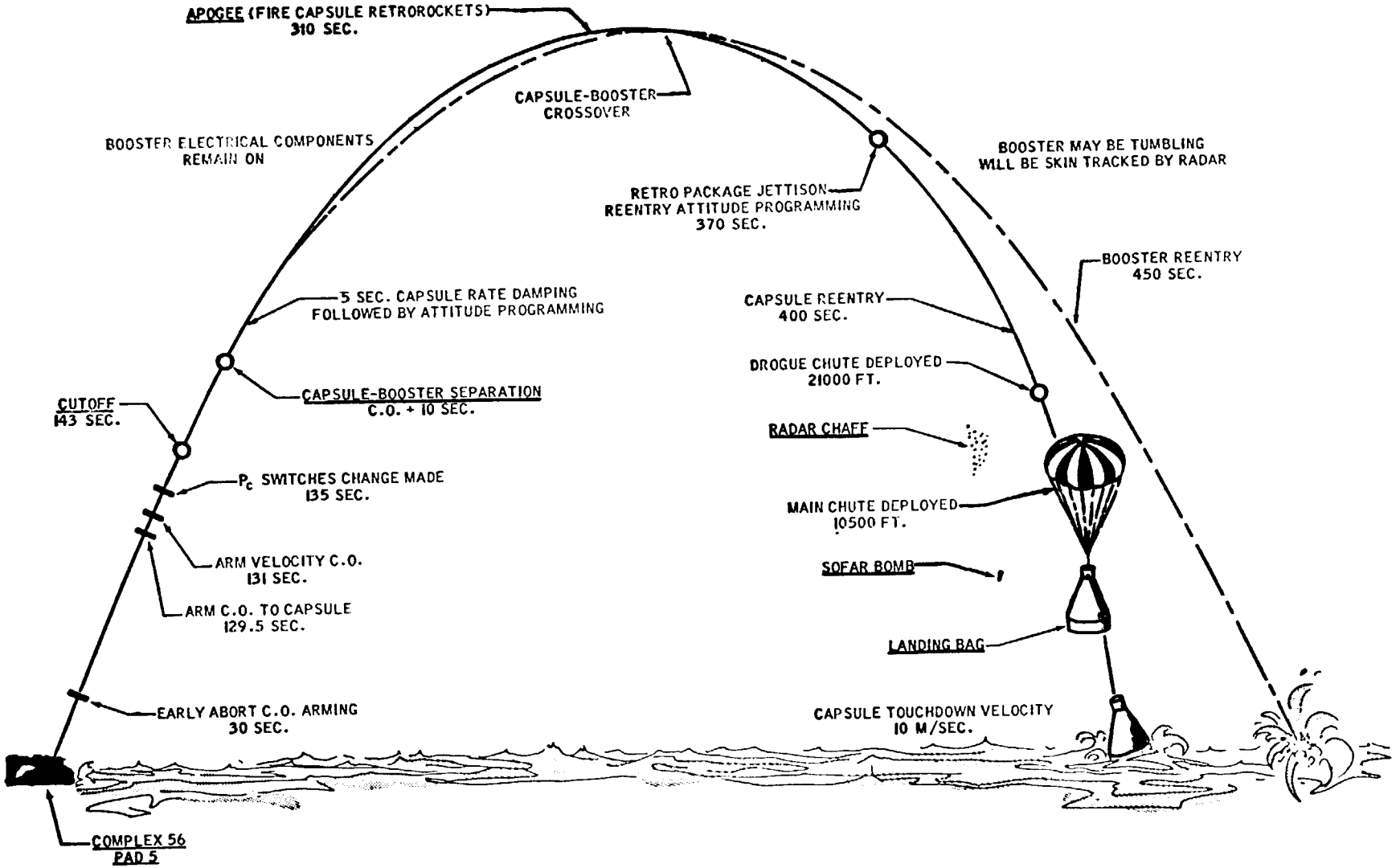



Figure 3-4. Typical Flight Profile, MERCURY-REDSTONE

At shutdown (143 seconds), the abort system was deactivated and the escape tower jettisoned. This occurred 9.5 seconds before capsule separation. Figure 3-5 is a block diagram of the MERCURY-REDSTONE mission sequence.

Table 3-1

MERCURY-REDSTONE Mission Sequence of Events

| Event | Time After Liftoff (Seconds) |
|---|---|
| Liftoff | 0 |
| Begin tilt program (MR-1, -IA, and -2)<br>(MR-BD, -3, and -4) | 24.3<br>15.0 |
| Arm circuit for engine cutoff by abort system | 30.0 |
| Stop fuel tank pressurization | 70.0 |
| Special tilt arrest (MR-BD only) for 8 seconds | 78 |
| Arm cutoff circuit to capsule | 129.5 |
| Arm velocity integrator cutoff circuit | 131.0 |
| Tilt program arrest | 131.7 |
| Arm fuel depletion cutoff circuit (chamber pressure sensing switches changed to fuel depletion mode) | 135.0 |
| Nominal cutoff time (initiated by velocity integrator) | 142.5 |
| Escape tower separation and abort system deactivation | 143.0 |
| Capsule separation | Cutoff +9.5 |
| Nominal maximum altitude (booster) | 308.7 |
| Nominal maximum altitude (capsule) | 309.1 |
| Nominal capsule re-entry, maximum deceleration | 492.0 |
| Nominal capsule main parachute unreefed | 618.0 |
| Booster impact (MR-3 only) | 674.0 |
| Capsule impact (MR-3 only) | 922.0 |

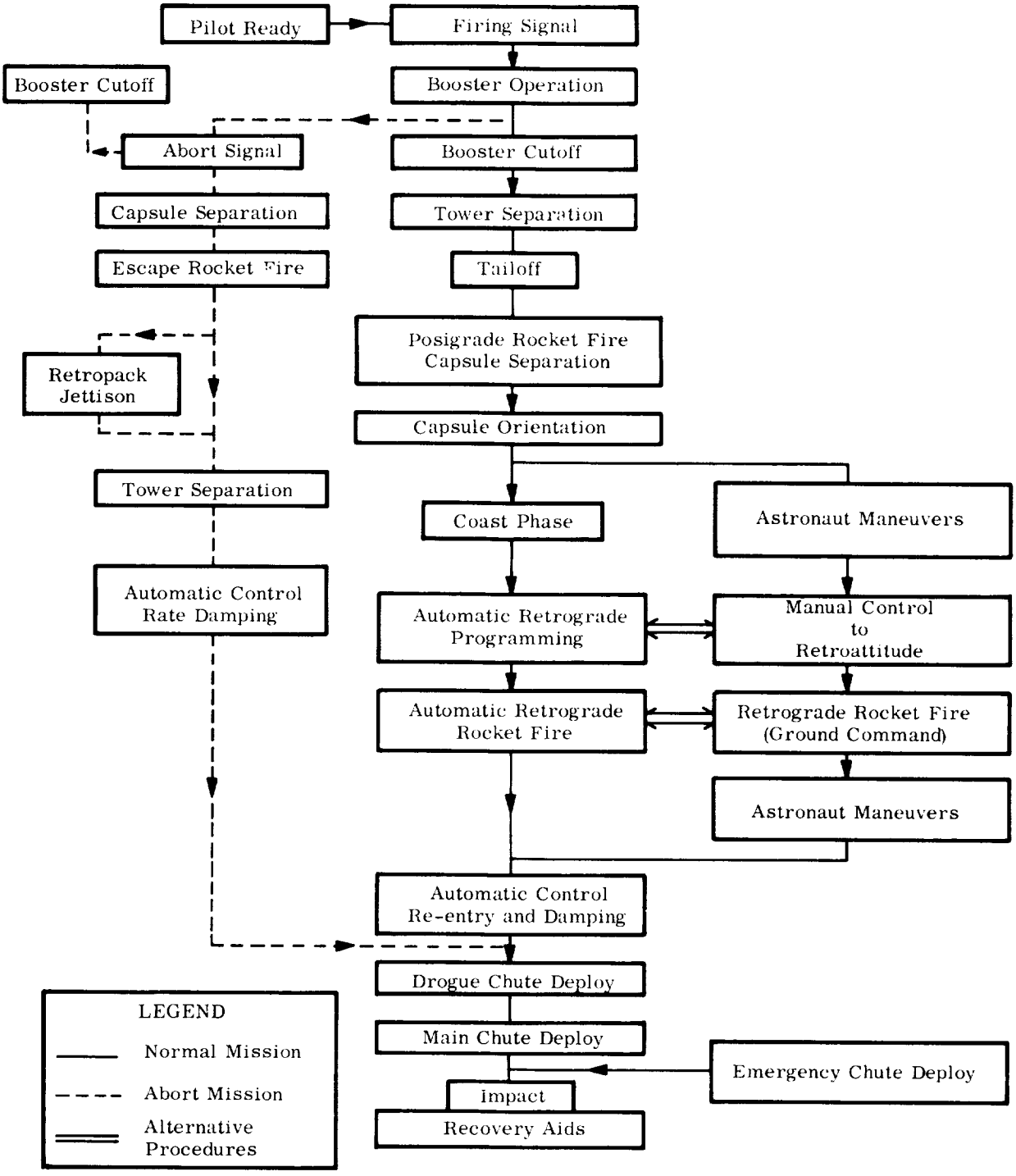



Figure 3-5. Block Diagram of MERCURY-REDSTONE Mission Sequence

SECTION 4

# VEHICLE DESCRIPTION

## 4.1 INTRODUCTION

The over-all 83.38-foot length of the MERCURY booster was made up from several booster units, shown in Figure 4-1. These units and the systems contained within them are described in this section.

## 4.2 STRUCTURE

### 4.2.1 GENERAL

The basic vehicle was primarily constructed with 5052 aluminum alloy using a semi-monocoque skin and a ring frame design with stringer longerons for additional support in the aft and tail units. Figure 4-2 shows the structure in an exploded view. The design factor of safety was 1.35 on the propellant tanks.

The structural weights were:

- Aft Section 437.4 lb
- Center Section 1659 lb
- Tail Section 902.6 lb
- Ballast 487 lb
- Dampening Compound 442 lb
- Blast Shield 15 lb

With airborne equipment installed, the total booster dryweight was 8195 pounds.

### 4.2.2 CENTER SECTION

The thrust load was transmitted from the engine to the center section by a four-strut frame. The skin of the center section was designed to transmit this load to the aft unit without stringers or pressurization. The aft unit, a name carried over from the tactical version, was attached to the forward end of the center or container unit with six fasteners in compression. The tail unit was attached to the container unit by 12 fasteners in tension.

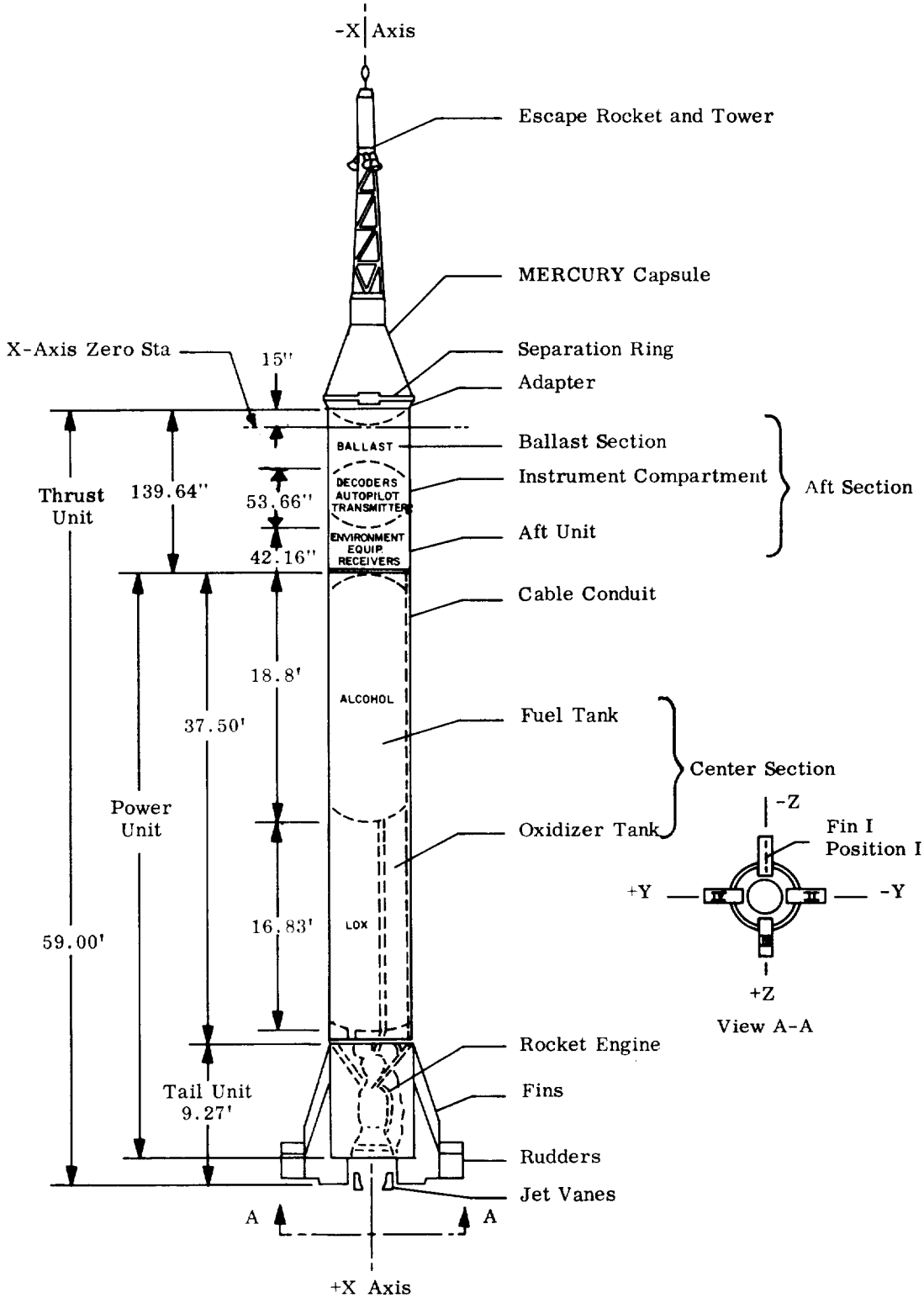
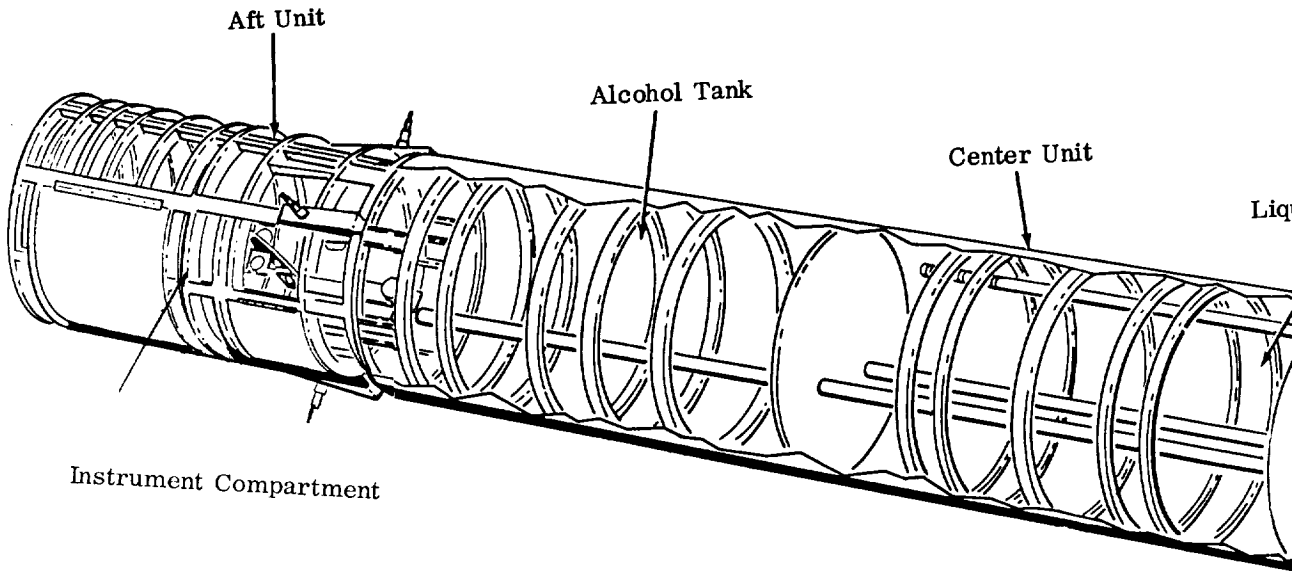



Figure 4-1. Booster Units


Aft Unit
Alcohol Tank
Center Unit
Liq
Instrument Compartment

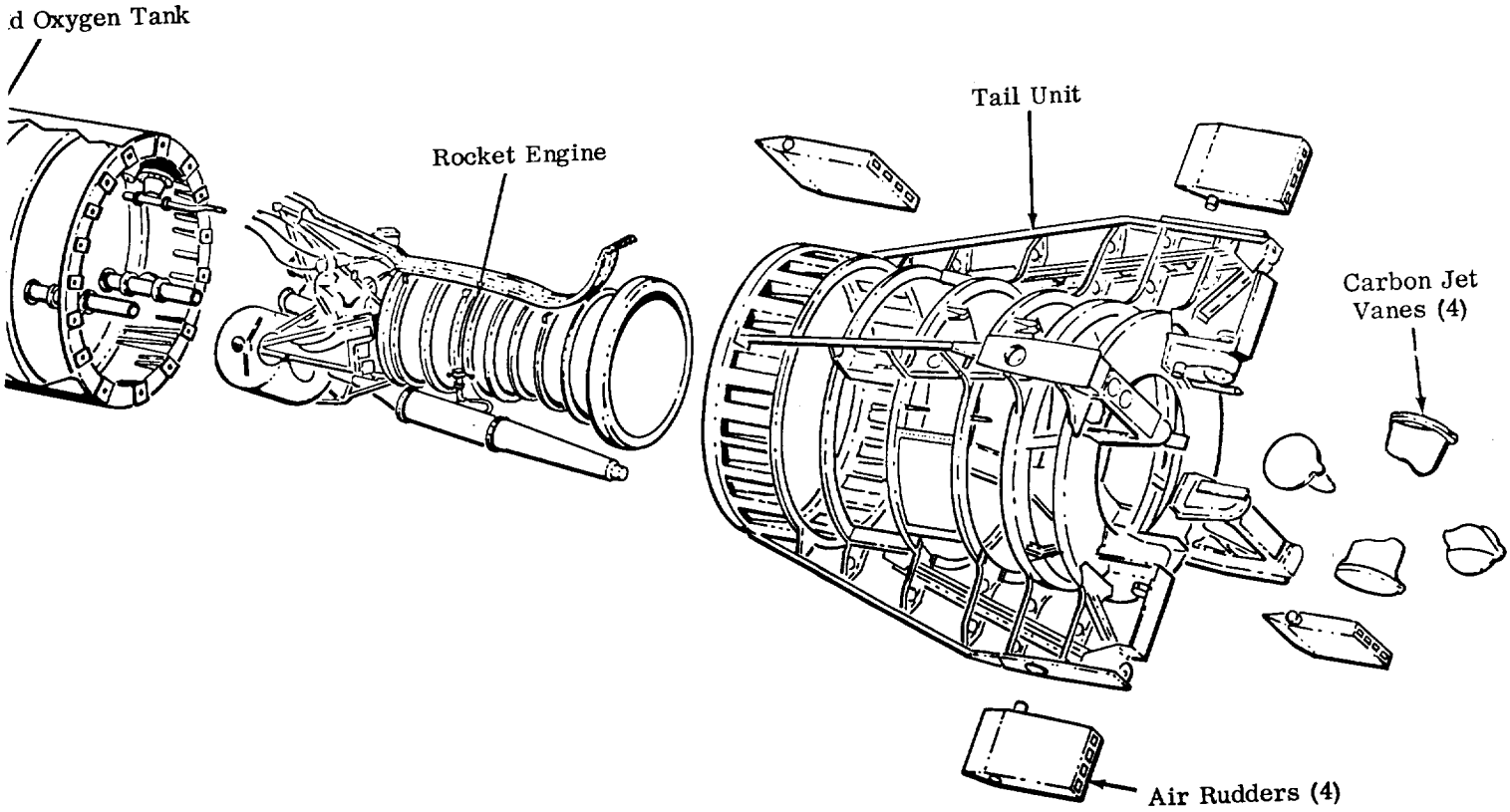



Figure 4-2. Exploded View of Launch Vehicle Structure

Skin thickness was 0.090 inch on the aft unit, 0.063 inch on the fuel tank, 0.080 inch on the LOX tank, and 0.125 inch on the tail unit. Glass wool was used to insulate the LOX tank bulkheads and the fuel feed line, which passed through the LOX tank.

The forward bulkhead of the center section was designed to withstand 25.3 psi during flight. The center bulkhead was common to both tanks and was designed for a minimum burst pressure of 95 psid (differential pressure) in the fuel to oxidizer direction. The bulkhead could also withstand 55.6 psid in the oxidizer to fuel direction without buckling. Burst pressure of the aft bulkhead was 90 psid. Nominal fuel tank pressure was 18.5 psig, vented at 22 ± 5 psig. Nominal oxidizer tank pressure was 19.5 psig, vented at 32 ± 1 psig. Nominal fuel volume was 3348 gallons, and nominal oxidizer volume was 3072 gallons.

### 4.2.3 AFT SECTION

Forward of the container section was the 139.64-inch-long aft section. Positioned in the center of the aft section, and 53.66 inches in length, was the pressurized instrument compartment. The ballast section was above the compartment, and below it was the aft unit containing the nitrogen pressurizing system and communication antennas and receivers.

The instrument compartment had four access doors and was both pressure and temperature controlled. Located in the compartment were instrumentation and power supplies associated with the control system, the vehicle's electrical system, the telemetry system, the abort system, and the command destruct system. These instruments were mounted on a T-shaped structure consisting of two plates at right angles to each other.

Compartment pressurization was maintained between 12 and 15 psia during flight by a check-valve controlled nitrogen gas system. During preflight checkout, the electronic equipment within the compartment generated approximately 3.5 kilowatts of heat, thus an 80 cfm air cooling system was required to maintain compartment temperature between 10° and 40° C.

Temperature was controlled by removing air from the instrument compartment through the missile drop-off plate, regulating the temperature of this air by means of a cooling

package mounted on a cable mast, and returning the cooled air to the compartment through a balanced distribution system. Regulation of the air temperature was affected by a temperature sensor control valve, which varied the air flow through the cooling package. Components of this system were the coolant container, blower, check valve, vent valve, control box, air temperature sensor, ducting dehumidifier, three-way valve, and thermoswitches.

### 4.2.4 TAIL UNIT

The tail unit consisted of the cylindrical section surrounding, but not including, the rocket engine. The air rudders and jet vanes were also parts of the tail unit. This unit was designed to support the entire launch vehicle while standing freely on the launch pedestal. The MERCURY-REDSTONE did not use hold down arms during launch.

Inside each fin and attached to the tail unit was a servomotor used to rotate the jet vane and air rudder. The servomotor was driven by electrical signals from the control computer located in the instrument compartment. Located within the upper portion of the tail unit were seven spheres containing high pressure gases for tank pressurization. The tactical missile had two sets of three tanks each. However, a seventh tank had to be added during the MERCURY-REDSTONE modification program to provide pressurization throughout the increased burning time of the engines.

Two hydrogen peroxide tanks used in the propulsion system were also located in this area. The second or auxiliary tank was also added because of the lengthened burning time.

Two connectors were located on the bottom of Fin II for mechanical and electrical power connections and grounding of the vehicle through the launch pedestal. These connections were the last ground-vehicle connections to be detached as the missile lifted off.

### 4.2.5 ADAPTER AND CAPSULE INTERFACE

The adapter was a conical section bolted to the aft unit which provided the interface between the launch vehicle and the capsule. The capsule was attached to the booster adapter with the capsule adapter-clamp-ring retaining device. The clamp ring secured the lower edge of the capsule to the upper edge of the adapter. The ring had three segments which were fastened together by explosive bolts. The bolts were wired

separately to provide redundant ring cutting. Each bolt was covered by a shield to prevent fragments of the severed bolt from striking the capsule or booster.

To assure proper electrical continuity between the adapter and the capsule, interface templates were used to mount two electrical plug connectors.

The physical separation of the booster and capsule was accomplished by firing the capsule's posigrade rockets. However, to be effective, the booster had to be in the cutoff condition with little, if any, residual thrust. Zero thrust was to be expected about 3.2 seconds after booster engine cutoff. Residual thrust from the LOX venting did not interfere with the separation since the LOX vented at low force and in a direction perpendicular to the longitudinal axis of the vehicle. The posigrade rockets, which extended into the ballast section, fired into the upper end of the aft unit and filled the ballast section with gas. The gas pressure further helped the separation by pushing the capsule away from the booster. The Lewis Research Center, NASA, conducted tests and determined that this gas increased separation velocity by approximately 25 feet per second.

## 4.3 PROPULSION SYSTEM

### 4.3.1 GENERAL

The propulsion system was composed of the rocket engine, propellant feed system, and the hydrogen peroxide and pneumatic subsystems. These were contained within the tail unit and attached to the container section by four thrust struts. The propulsion system and flight control at the beginning and end of the thrust period was achieved by deflection of carbon vanes inserted into the exhaust of the engine.

The subsystems and components of this system are described in the following paragraphs.

### 4.3.2 ROCKET ENGINE

The Rocketdyne Model A-7 engine (Figure 4-3) was the powerplant for the MERCURY-REDSTONE launch vehicles. Basically it was the same powerplant as used in the latest tactical REDSTONE missiles with modifications to improve operational efficiency and safety. The engine generated 78,000 pounds of thrust at sea level. The propellants used were ethyl alcohol and liquid oxygen. The turbopump was driven by hydrogen peroxide.

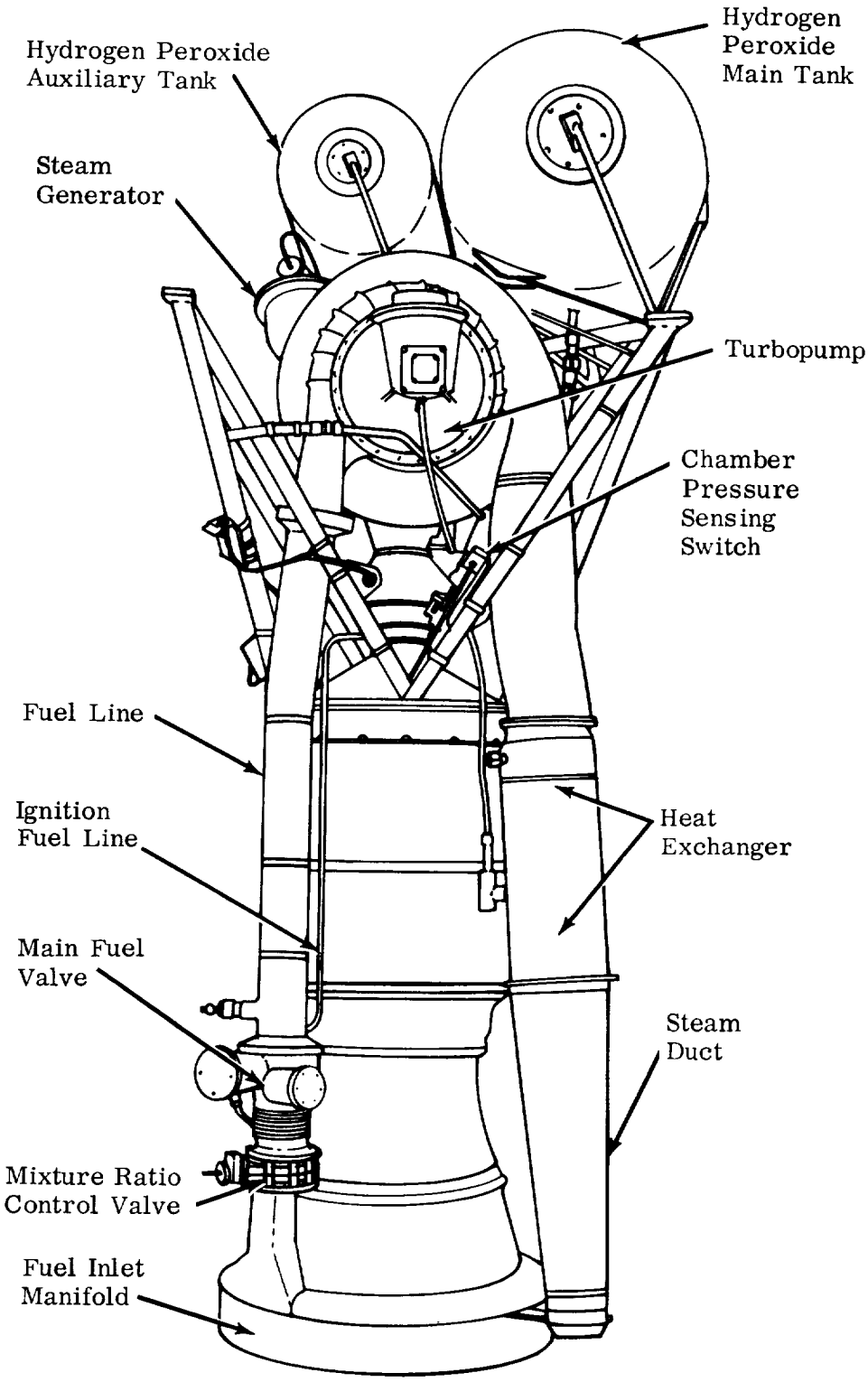



Figure 4-3. A-7 Rocket Engine

The engine starting sequence was initiated from a ground source by a manual firing command signal. Figure 4-4 illustrates the main actions leading to mainstage burning. Liftoff occurred when approximately 85 percent of rated thrust was attained.

The thrust level of the engine was maintained at a specific magnitude by a thrust control system, which compared the actual thrust chamber pressure with a preset electrical null and regulated the flow of hydrogen peroxide into the gas generator. By controlling the flow of peroxide for producing gas the speed of the turbopump controlled the amount of propellants entering the thrust chamber.

Once started, engine operation normally continued until the vehicle had reached a predetermined velocity. When this velocity was attained, an integrating accelerometer emitted a signal that initiated an automatic cutoff sequence (Figure 4-5). This sequence consisted essentially of closing the peroxide, main LOX, and fuel valves to stop the engine. As pressure in the thrust chamber decreased, a signal started a timer in the capsule which ultimately triggered capsule separation.

### 4.3.3 PROPELLANT FEED SUBSYSTEM

The propellant feed subsystem delivered propellant to the engine at the required pressures and flow rates. The system also included provisions for ignition fuel control.

From their tanks, LOX and fuel passed through the turbopump, main valves, and control orifices to the engine. The turbopump consisted of a steam driven, two stage, compound turbine; a geared speed reduction unit; and two centrifugal propellant pumps. Both pumps operated at the same speed. The turbine ran at a nominal 4800 rpm. Maximum safe speed was 6000 rpm. Minimum allowable fuel inlet pressure was 16 psig, and minimum oxidizer inlet pressure was 23 psig.

During ignition, LOX at tank pressure plus static head was mixed in the combustion chamber with pressure-controlled ignition fuel from an external ground supply. This method resulted in a controlled oxidizer-rich ignition.

### 4.3.4 HYDROGEN PEROXIDE SUBSYSTEM

The hydrogen peroxide subsystem drove the turbopump. Hydrogen peroxide concentrated to 75 percent was fed at 1.28 pounds per second from the $H_2O_2$ tanks to the steam generator where it was chemically decomposed into steam. The steam at approximate

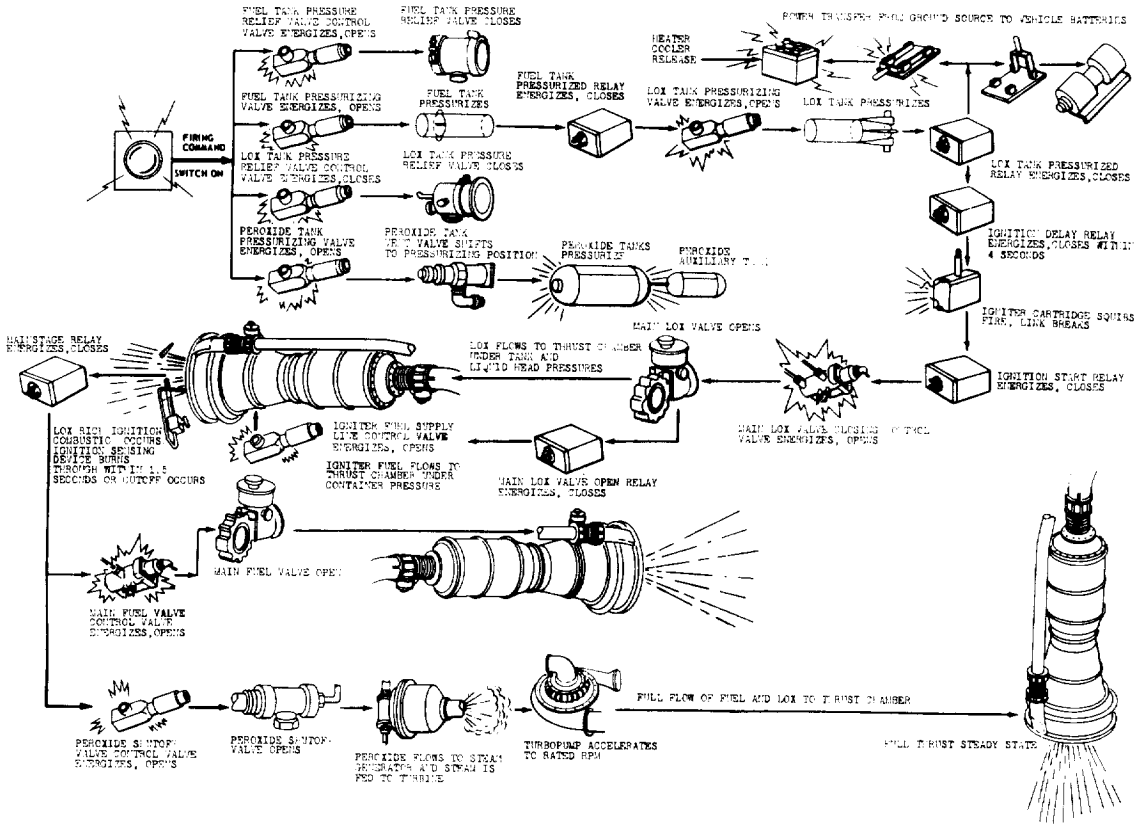



Figure 4-4. Engine Starting Sequence Diagram

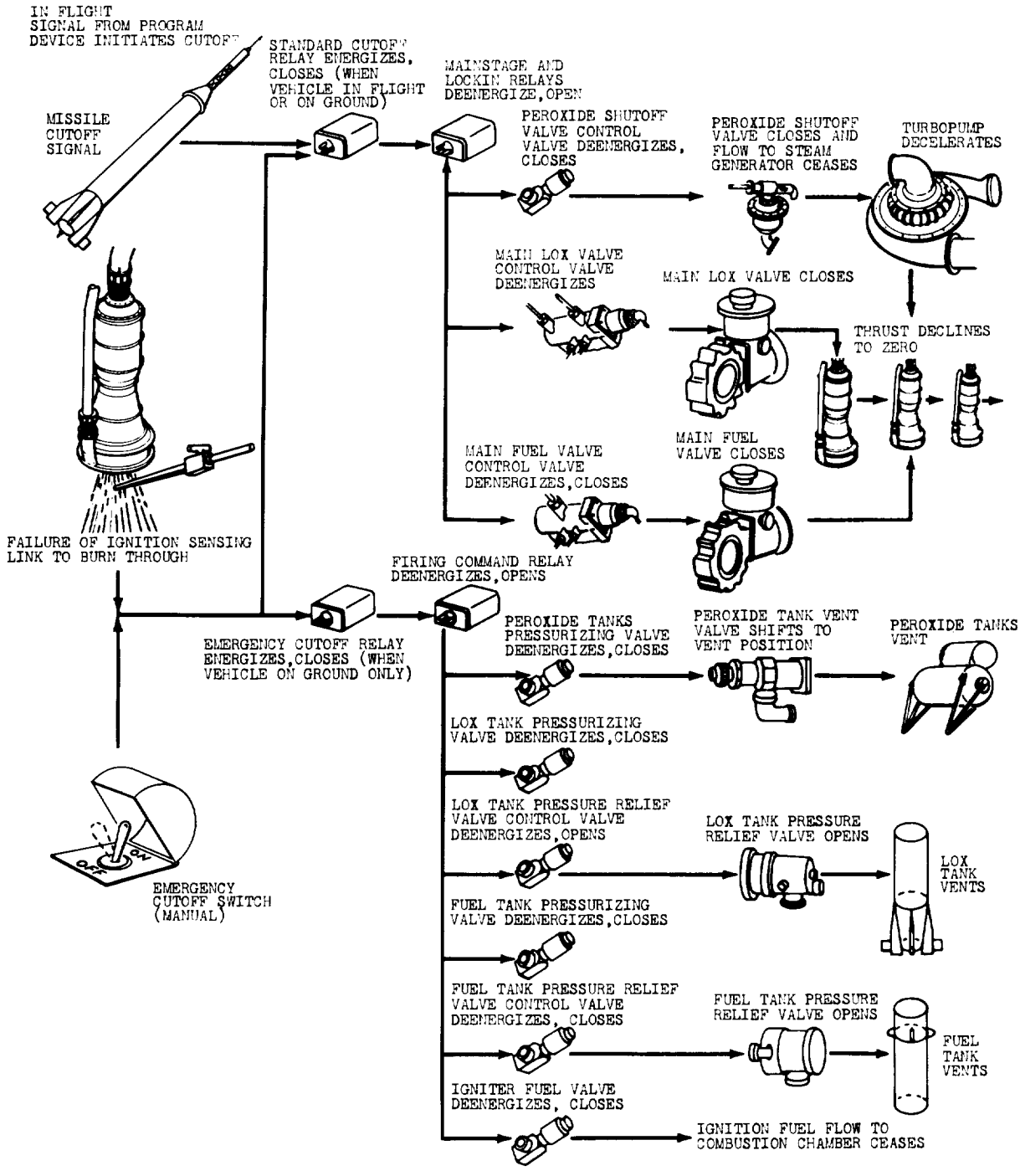



Figure 4-5. Engine Cutoff Sequence Diagram

740° F and 385 psi, was passed through the turbopump, and exhausted through the LOX and pneumatic system heat exchanger.

### 4.3.5 PNEUMATIC CONTROL SUBSYSTEM

The pneumatic control subsystem (Figure 4-6) provided gaseous nitrogen, at a nominal 580 psi, to operate propellant and peroxide valves and to pressurize the peroxide tanks. A tap on the system provided preflight and inflight fuel tank pressurization. LOX tank pressurization and control were also maintained during preflight by gaseous nitrogen, but inflight pressurization was maintained by LOX converted to gaseous oxygen in the heat exchanger. Prior to liftoff, a ground source of pressurized gaseous nitrogen operated the subsystem and supplied nitrogen for the tail section purging (to remove moisture and any volatile gas accumulations) and for fuel line bubbling (to keep the fuel temperature above freezing).

## 4.4 CONTROL SYSTEM

### 4.4.1 GENERAL

The MERCURY-REDSTONE Launch Vehicle control system maintained the proper attitude of the vehicle throughout the flight. This was accomplished by establishing and maintaining three reference axes and indicating, through error voltages, any deviation from the programmed flight. The two major gyros were the pitch gyro and the yaw-roll gyro. An integrating accelerometer (gyro type) gave a cutoff signal to the propulsion system when the predetermined velocity had been attained.

Carbon jet vanes located in the exhaust of the propulsion unit, coupled with the air rudders, were utilized to control the attitude of the vehicle. At liftoff, the jet vanes deflected the hot exhaust gases of the rocket to provide control and stability until the vehicle gained sufficient speed for the air rudders to become effective. Later, when the vehicle reached the rarified upper atmosphere and the rudders lost their effectiveness, the jet vanes again exerted the greater controlling influence.

Figure 4-7 illustrates the operation of the system in block diagram form. As shown, the system was composed of the LEV-3 stabilizer system control computer, control relay box, program device, flight sequencer, and four electro-mechanical actuators with feedback.

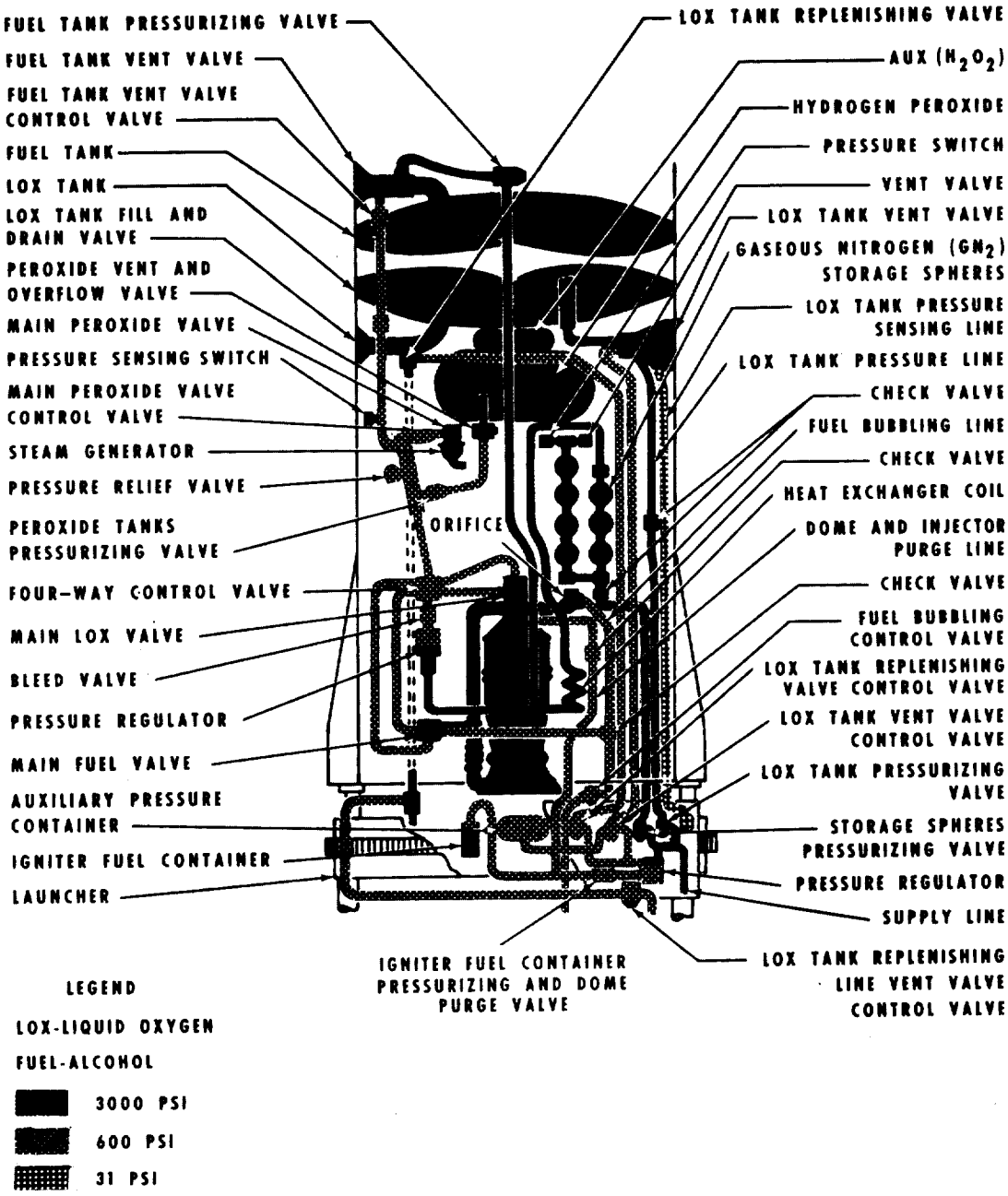



Figure 4-6. Pneumatic System

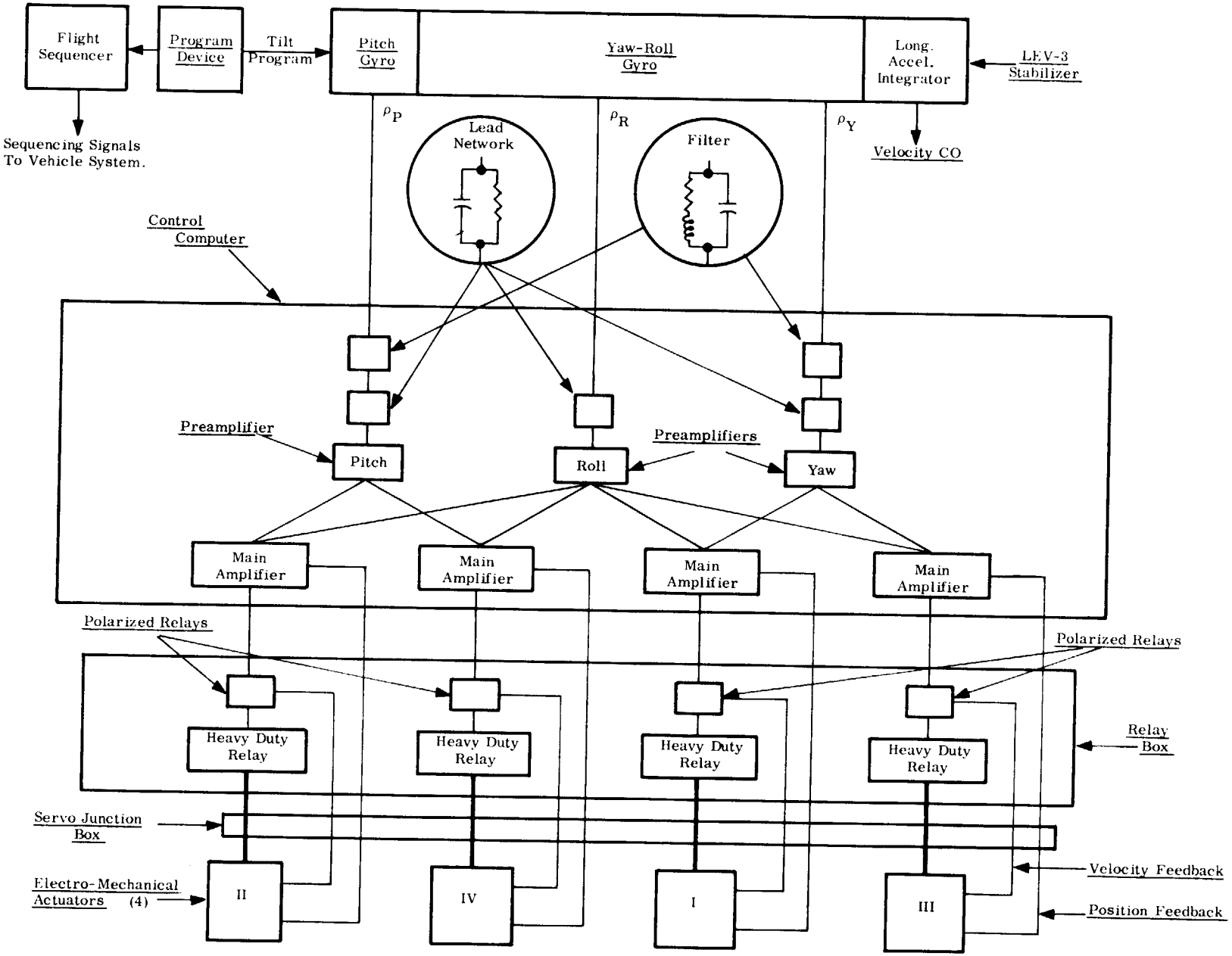



Figure 4-7. Details of Booster Control System

### 4.4.2 SYSTEM OPERATION

The control system was essentially an autopilot. It did not navigate nor guide the vehicle, but provided the necessary attitude program. During the powered phase of flight from 24 seconds to 131.5 seconds after liftoff, the tilting of the vehicle was controlled by the LEV-3 pitch gyro. Figure 4-8 shows diagrammatically the operation of the pitch gyro and the plane in which tilting occurred. The program device fed a continuous series of pulses to the stabilization system, causing the zero position of the pitch potentiometer to shift. The control system, recognizing this shifting zero point as an attitude error signal, caused the vehicle to tilt over until the wiper on the potentiometer was aligned to the new zero. The pitch programming was the means by which the vehicle was made to align its longitudinal axis with the gravity turn trajectory in order to fly without angle of attack measurement.

Tilt angles of only whole degrees, or multiples thereof, were possible. The minimum time required between tilting pulses for single tilting steps of one degree was set to allow a desired tilting rate of 0.67 degree per second. Figure 4-9 shows the pulse program for tilting.

A velocity integrator was used to signal engine thrust cutoff when the proper vehicle velocity was reached. The integrator, a gyro precessed by the gravitational and vehicle acceleration fields, sent the cutoff signal through pickoffs when the calibrated precession angle was reached.

### 4.4.3 LEV-3 STABILIZER SYSTEM

The LEV-3 stabilizer system (Figure 4-10) consisted of pitch and yaw-roll gyros, an integrator gyro within a junction box, and a shock mounted, gimballed baseplate. The system provided the reference frame from which vehicle attitude and acceleration were measured.

The two attitude gyros established and maintained three mutually perpendicular reference axes from which vehicle deviations in pitch, yaw, and roll were measured by means of potentiometer pickoffs. The pitch potentiometer was not fixed but was mechanized to the program device (refer to paragraph 4.4.2.) The rotor of each gyro was also the rotator of a synchronous motor, driven by a 400 cps power source; the synchronous motor's rotating field (stator) had an equivalent angular velocity of 24,000 rpm. Slip between the stator and rotator was 2000 rpm, resulting in a gyro

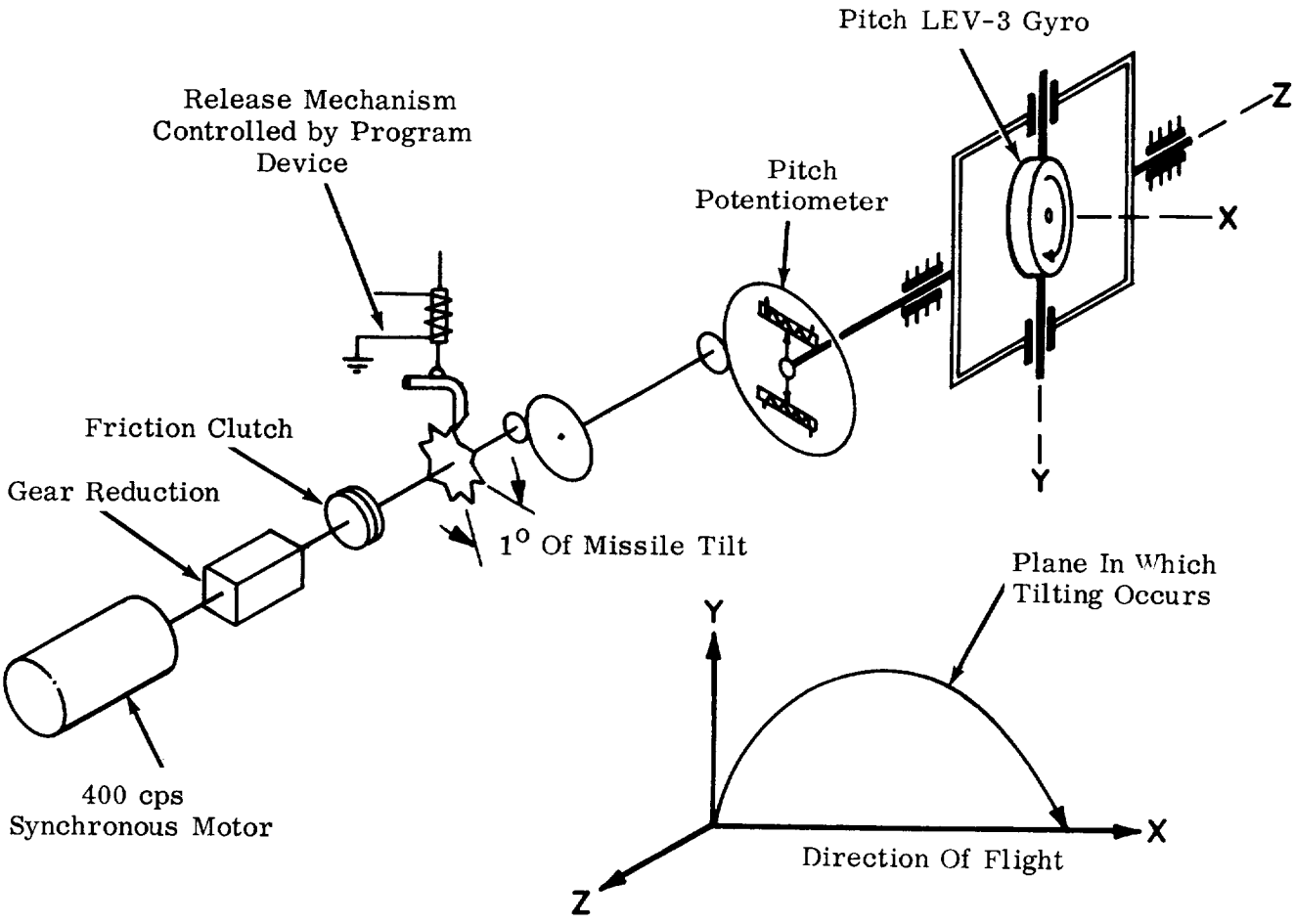



Figure 4-8. Mechanics of Tilting Program

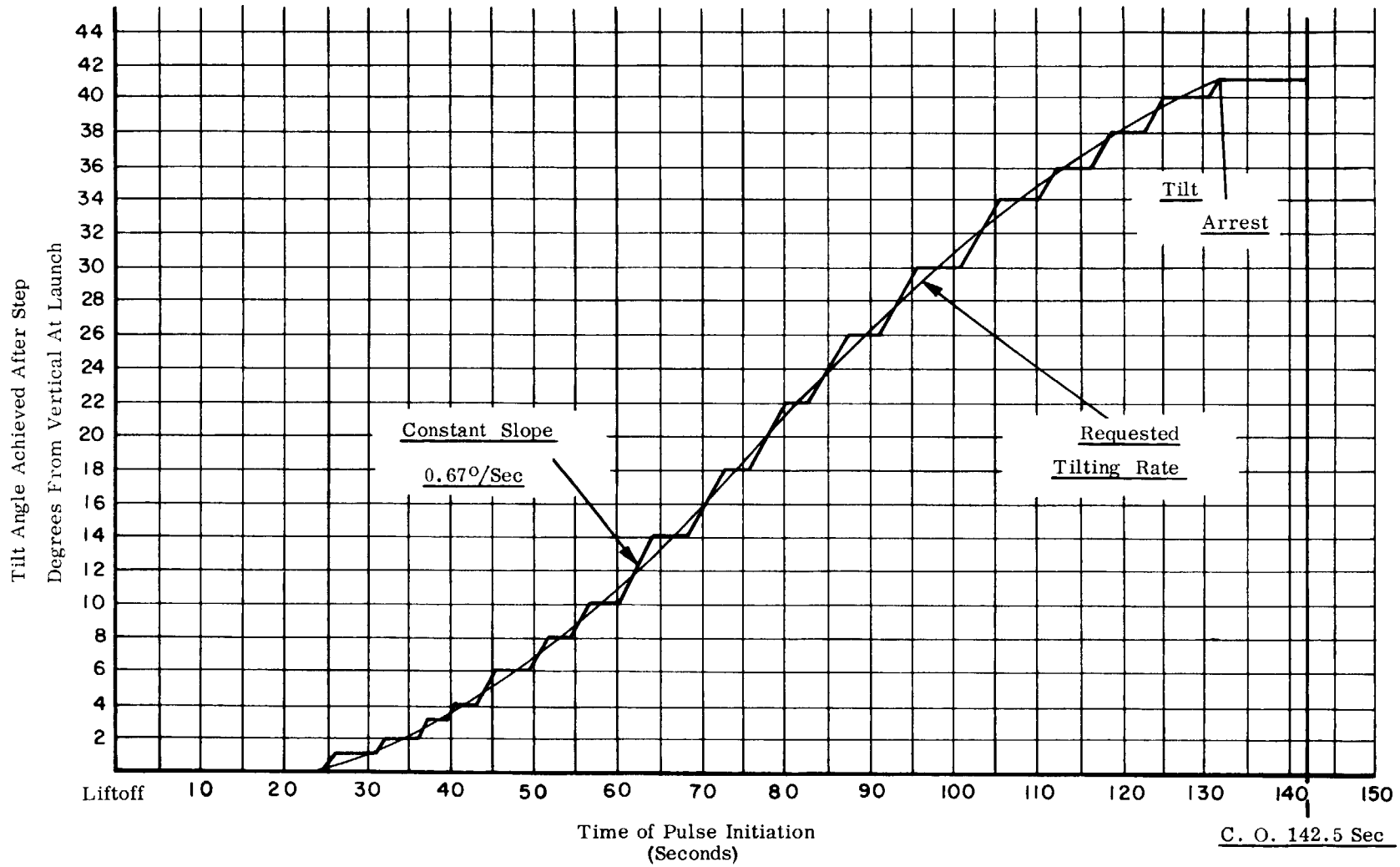



Figure 4-9. Pulse Program for Tilting

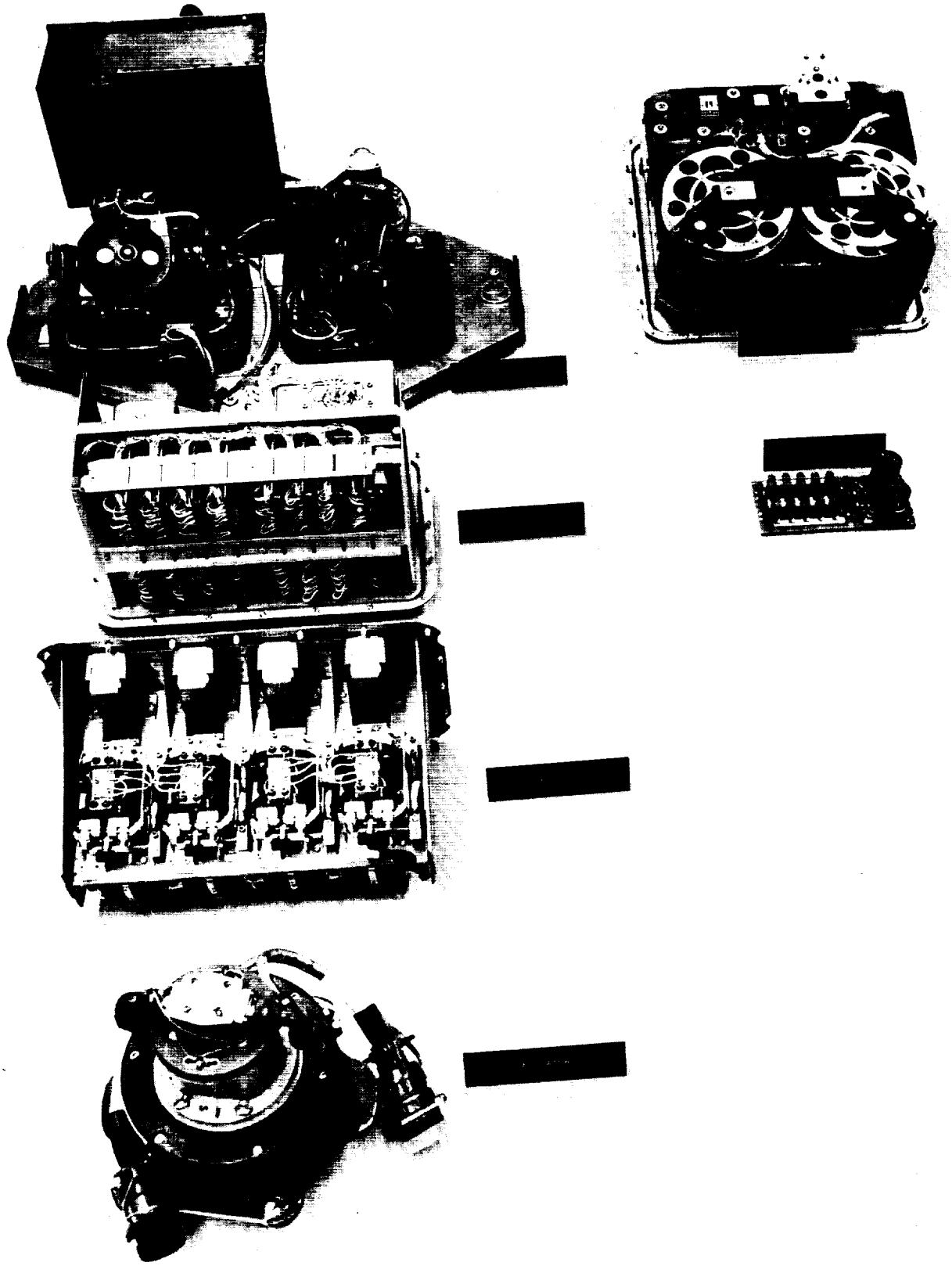


Figure 4-10. MERCURY-REDSTONE LEV-3 Stabilizer System

spin of 22,000 rpm. The gyro wheel weighed 1.5 pounds and had an angular moment equal to 12.106 gm-cm$^2$ per second.

Each gyro had a self-erecting element to provide erection prior to liftoff. This element precessed the gyro until the spin axis was perpendicular to the local vertical. Thus, the gyros were not necessarily parallel to the earth's surface or vehicle's longitudinal axis.

The integrator gyro was pivoted at one end of its spin axis and mounted within a junction box containing switching relays. This pivoting allowed the gyro to be precessed as the launch vehicle accelerated. The number of revolutions precessed was proportional to the integral of the acceleration sustained, and, therefore, a measure of the velocity. The output of the gyro indicated both vehicle and gravitational acceleration; the latter was subtracted out by the control computer. The revolution of the gyro was picked up by eight contacts mounted on the gyro case. The signal was transferred from the gyro case by eight flexible coils of wire passing through the hinge line.

### 4.4.4 CONTROL COMPUTER

The control computer was a magnetic summing amplifier which contained filters, RC networks, preamplifiers, main amplifiers, and a power supply. Its function was to receive the attitude error signals from the LEV-3 system, filter them to eliminate bending influences, differentiate them to obtain angular velocity signals, sum and amplify them, and distribute them to the proper channels of the control relay box.

### 4.4.5 CONTROL RELAY BOX

The control relay box consisted mainly of four sets (channels) of relays, each set having a signal sensing (polarized) relay and power distribution (heavy duty) relay. The polarized relay received command signals from the control computer, closed its contacts according to the polarity of the signals and thereby energized the proper set of coils in the heavy duty relay. The heavy duty relay contacts when closed, supplied 28 vdc power to the actuator motor, which drove the jet vane-air rudder combination. The actuator velocity signal was fed back to the polarized relay to prevent actuator overshoot. The actuator also had limit switches which interrupted the 28 volt servo power (de-energized the heavy duty relay coils) when the actuator reached preset travel limits.

### 4.4.6 PROGRAM DEVICE

The program device was an extremely precise, three channel magnetic tape device which provided an accurate onboard clock during the vehicle's flight. It was started at liftoff and during flight provided the tilt program pulses, the vehicle sequencing pulses (through the flight sequencer) and the master telemeter calibration pulses. A principal feature of this unit was the ease and speed with which the program could be changed.

### 4.4.7 FLIGHT SEQUENCER

The flight sequencer received command signals from the program device and distributed them to the vehicle's electrical system in a single train of time pulses by means of a series relay chain. The following pulses were sequenced as follows:

- 30 seconds — Arm abort system engine cutoff.
- 70 seconds — Stop fuel tank pressurization.
- 129.5 seconds — Arm cutoff to capsule.
- 131 seconds — Arm velocity cutoff.
- 135 seconds — Arm fuel depletion cutoff.

### 4.4.8 ROTARY ACTUATORS

The actuators were electro-mechanical devices which converted electrical energy into mechanical energy by a series of gears driven by a dc motor. Each of the four actuator units consisted of a one horsepower dc servomotor, a gear train, a vane position feedback potentiometer, and limit switches on the potentiometer, set at ±27 degrees. Signals proportional to the vane position and velocity were obtained from each feedback potentiometer.

Actuator position was fed back to the control computer to cancel out the input error signal when the actuator reached its commanded position. Actuator velocity was fed back to the polarized relay in the relay box to slow down the actuator as it neared its commanded position, thus preventing overshoot and control servo loop instability.

The carbon vanes and air rudders were operated by four identical rotary actuators which directly drove the carbon vanes and were coupled to the air rudders by a chain and sprocket drive. The maximum possible deflection for the carbon vanes was ±27.5 degrees and ±11 degrees for the air rudders.

## 4.4.9 VEHICLE DYNAMICS

Two aspects of the vehicle dynamics are considered in this section, normal flight and control malfunctions.

During normal flight, maximum dynamic pressure occurred at 80 seconds after liftoff with cutoff following at 143 seconds (see paragraph 3.2). Throughout this period the center of gravity and center of pressure shifted as shown in Figure 4-11 such that the static margin passed through zero at 89 seconds. At this point the vehicle became aerodynamically unstable. The time at which the instability began would have been earlier had not 487 pounds of ballast and 442 pounds of dampening compound been added to the aft section.

The flight bending moment distribution is shown in Figure 4-12 and the lateral bending modes in Figure 4-13. Both rigid-body and rigid-plus-elastic body calculations are shown. The three sigma plot of bending moment was based on the wind velocities expected at the Cape. These wind velocities used in the calculations are shown in Figure 4-14, and were assumed to build up in the most unfavorable direction from 0 to maximum velocity at a rate of 0.05 meter per second per meter of altitude.

The natural bending frequencies of the MERCURY-REDSTONE were lower than those experienced by the tactical missile. These lower frequencies caused some feedback in the control system (see changes). The lateral bending frequencies are shown in Figure 4-15 and the longitudinal frequencies in Figure 4-16.

Angle of attack was calculated for both ultimate loading and that expected for a three sigma wind. Figure 4-17 shows that the smallest margin (1.5 degrees) occurred at 70 seconds and that at maximum dynamic pressure (Max Q), the margin had increased to over 2 degrees.

Malfunctions in the control system which could have led to a catastrophic damage within the shortest time, generally, would have resulted in control surface hardover. Therefore, jet vane-air rudder hardovers in yaw, pitch, and roll were studied. The effect of hardover on attitude angle is shown in Figure 4-18, on angle of attack in Figure 4-19, and on roll acceleration in Figure 4-20. Roll acceleration can cause a critical "eyes up" condition for the astronaut if the radial acceleration reaches 6 g's. Angle of attack and attitude angle changes were studied because they define the rate at which the vehicle approaches a breakup condition.

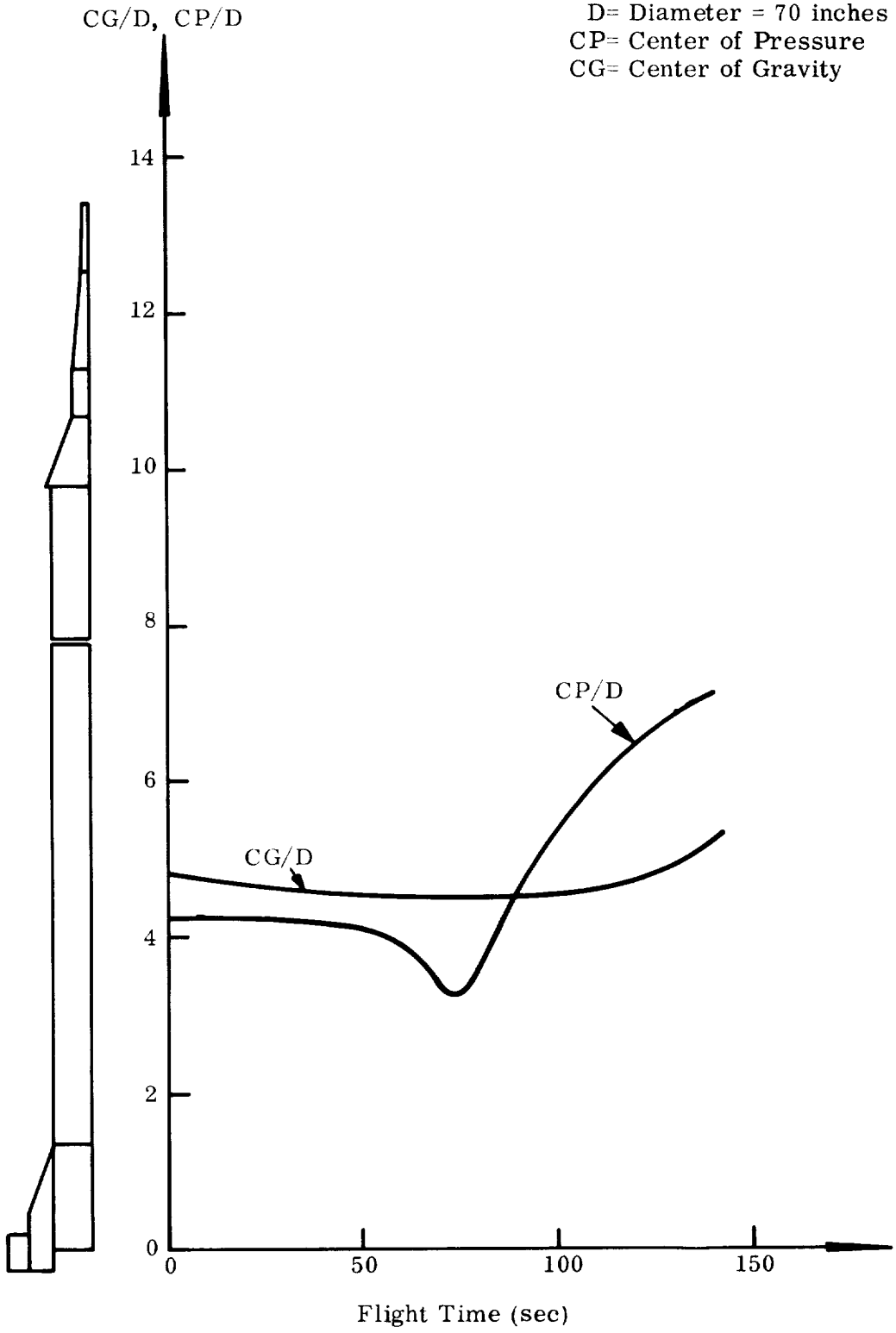



Figure 4-11. MERCURY-REDSTONE Center of Gravity and Center of Pressure Location During Time of Flight

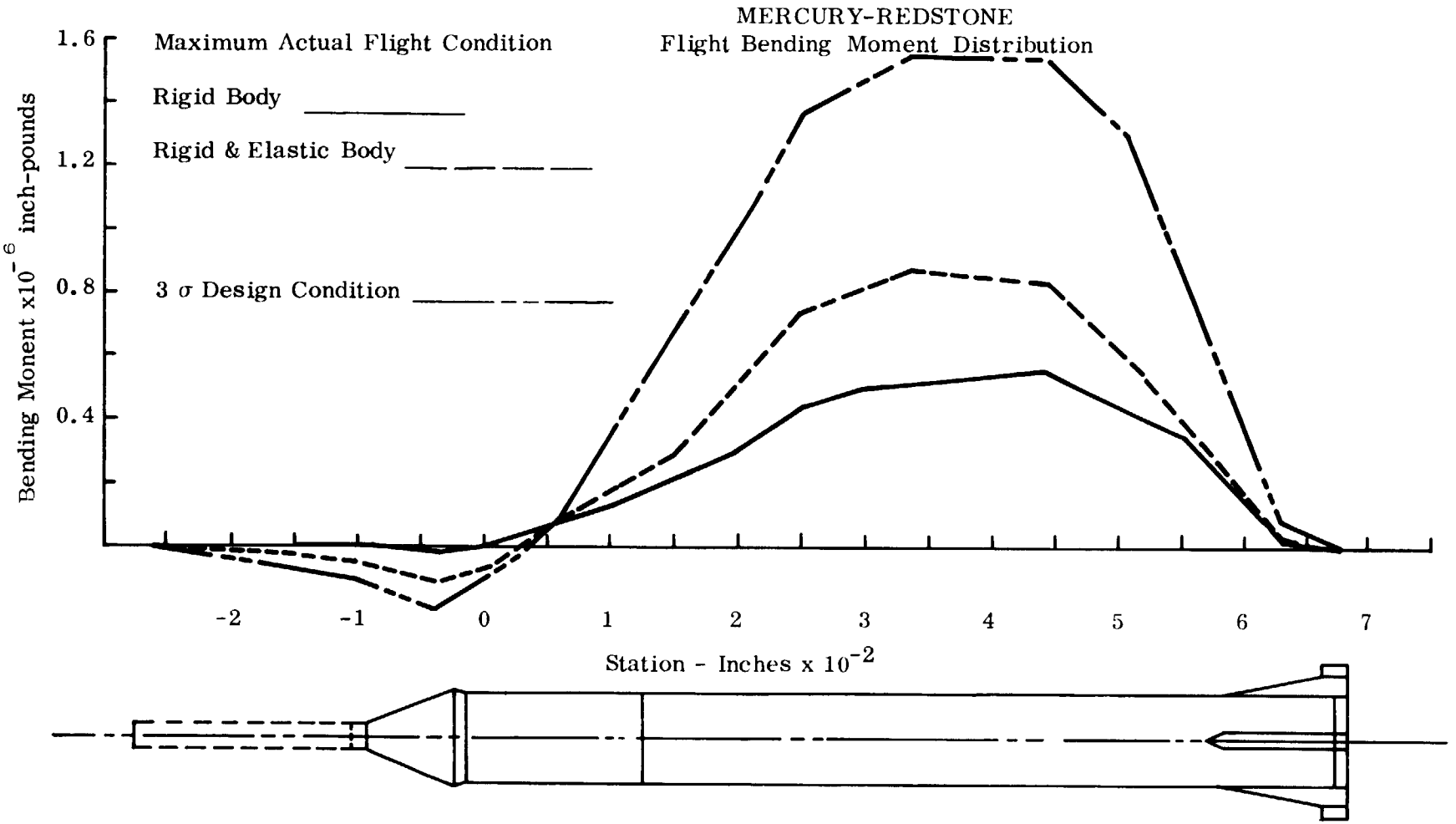



Figure 4-12. MERCURY-REDSTONE Flight Bending Moment Distribution T = 80 Seconds

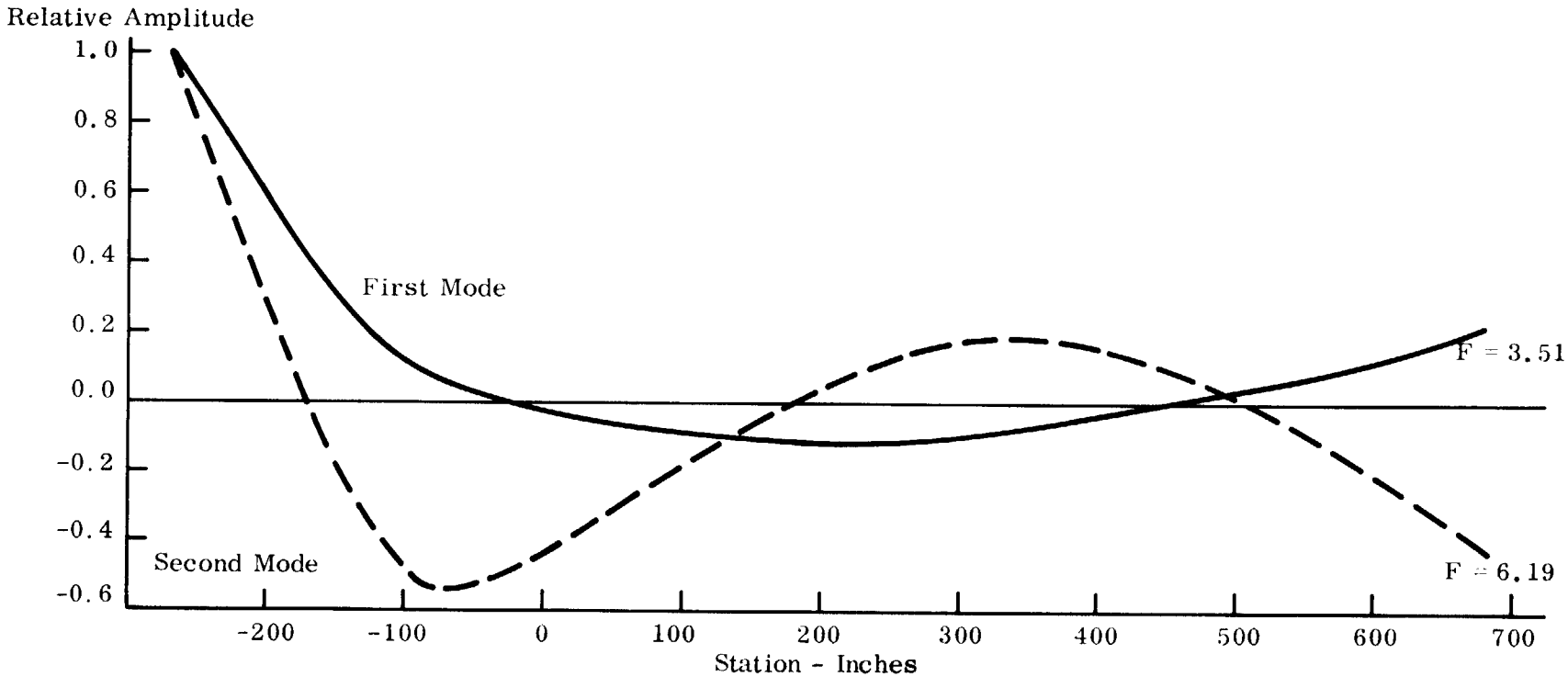



Figure 4-13. MERCURY-REDSTONE - Relative Amplitude versus Missile Station T = 60 Seconds Free-Free Lateral Bending Modes

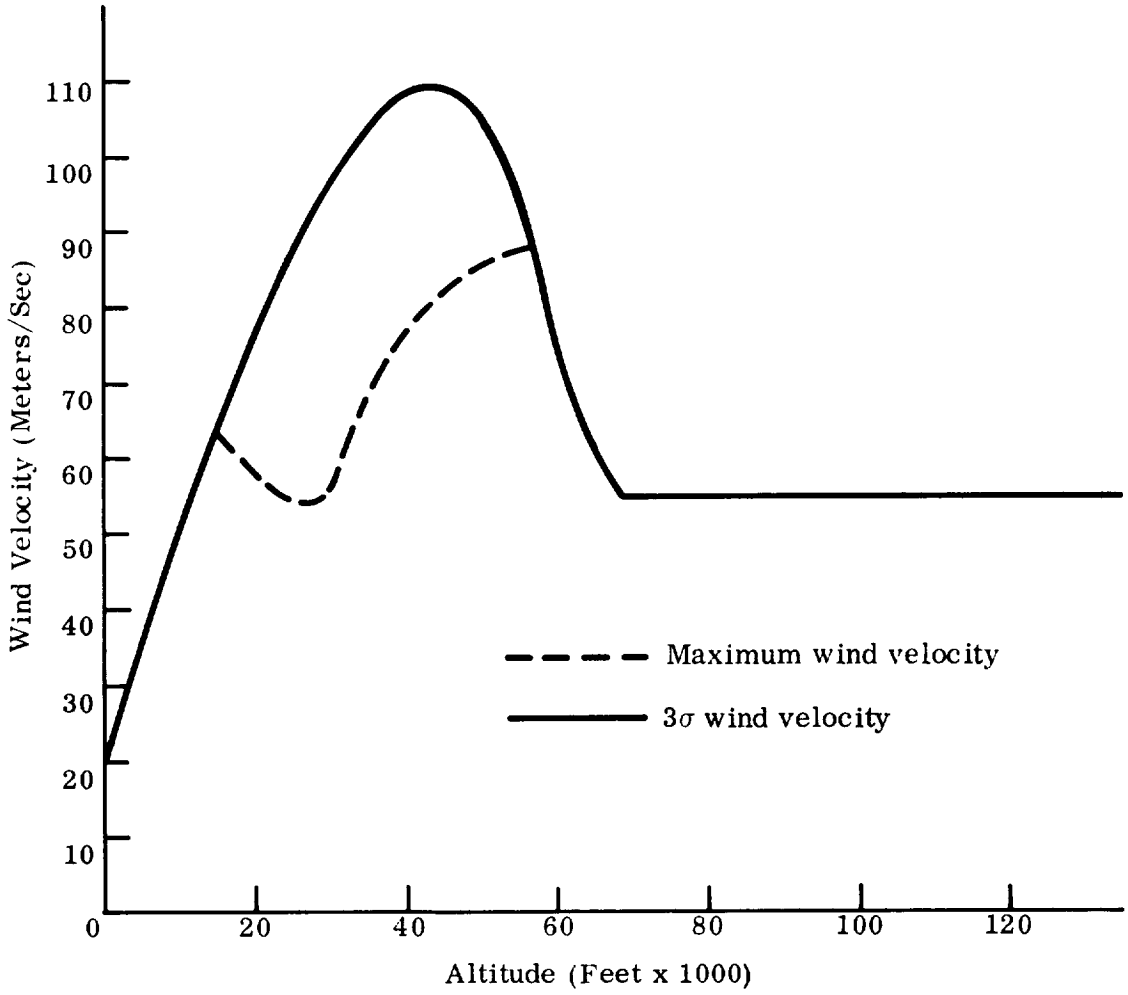



Figure 4-14. Maximum Design Wind Velocity versus Altitude

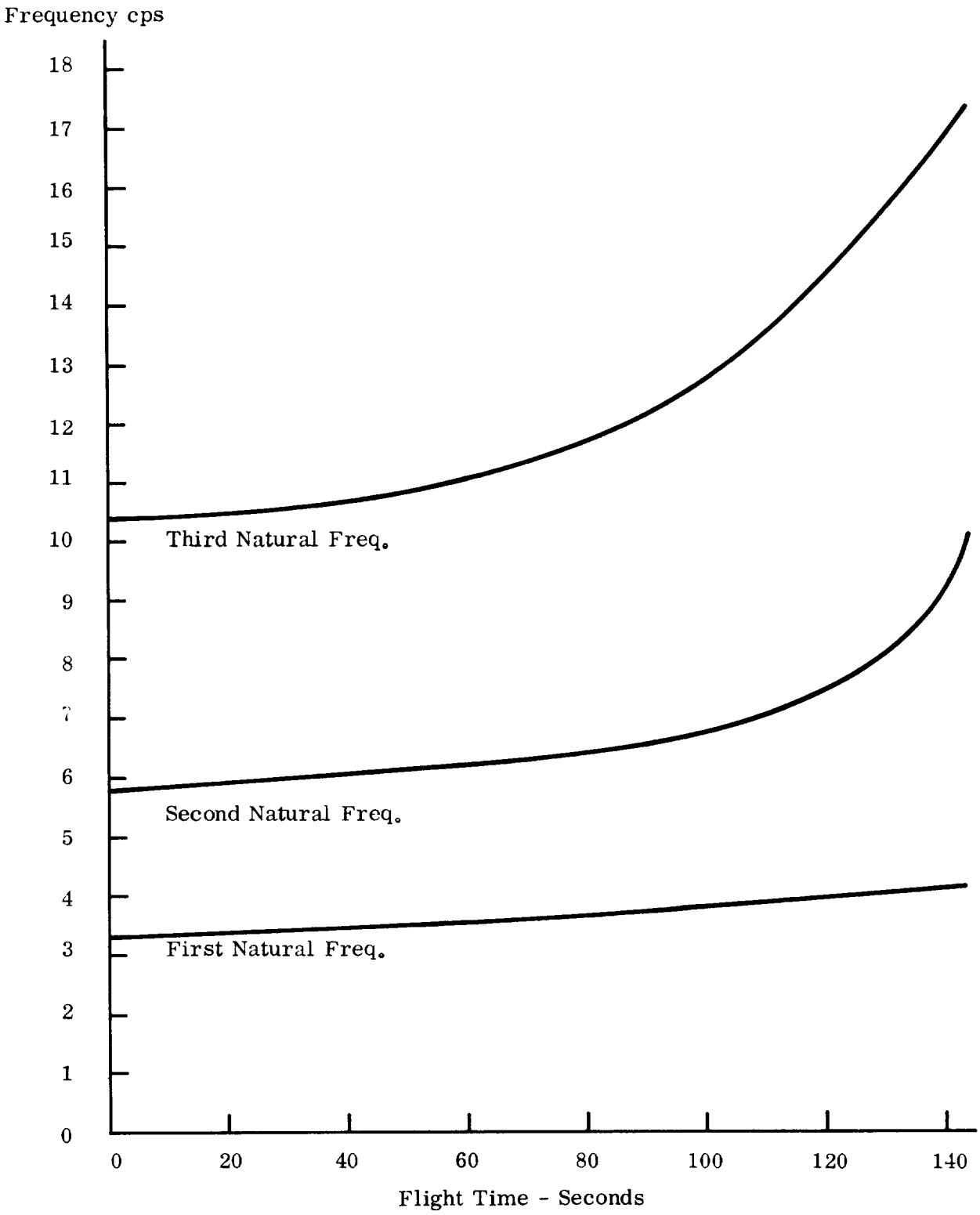



Figure 4-15. MERCURY-REDSTONE Free-Free Lateral Bending Natural Frequency versus Flight Time

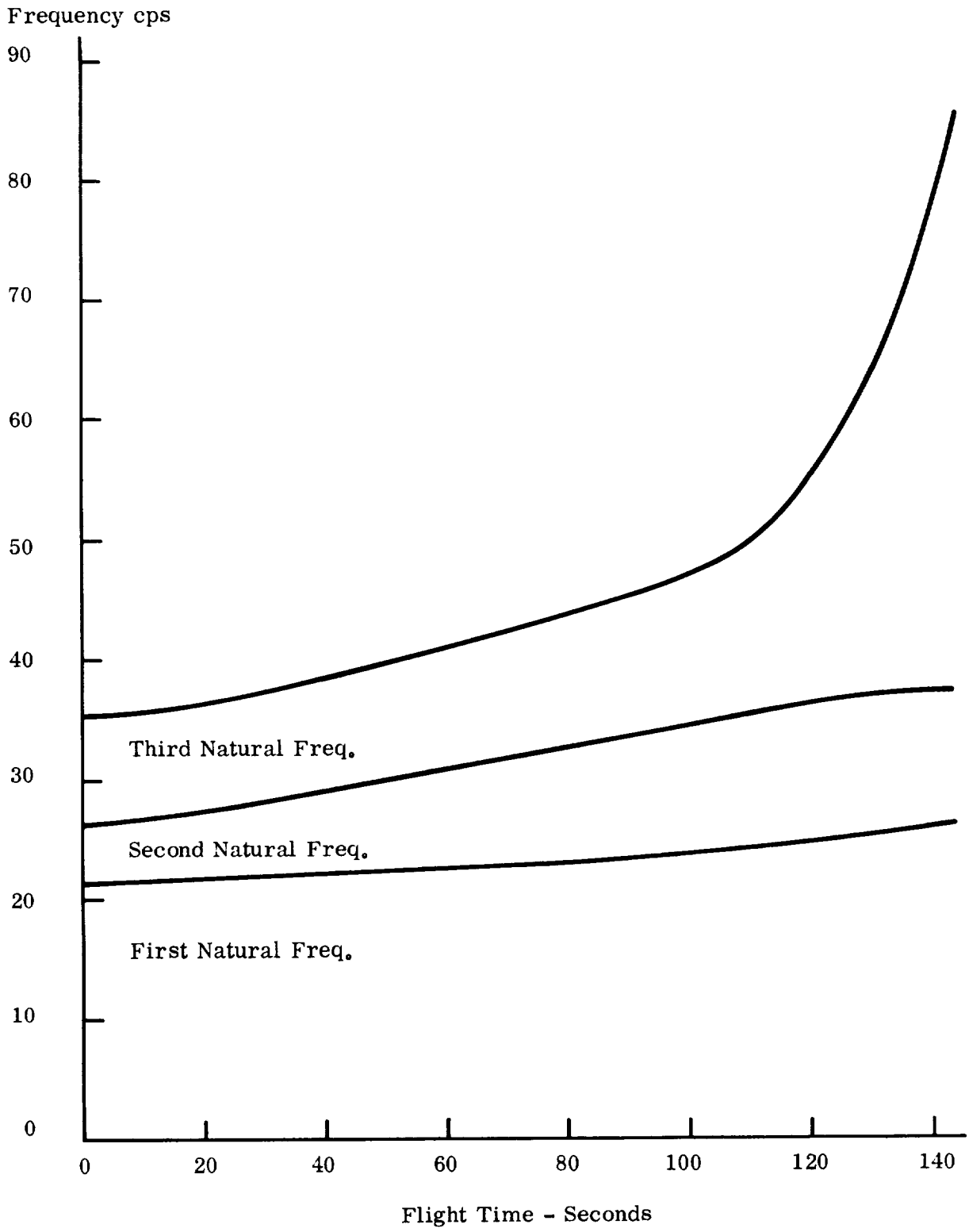



Figure 4-16. MERCURY-REDSTONE Free-Free Longitudinal Natural Frequency versus Flight Time

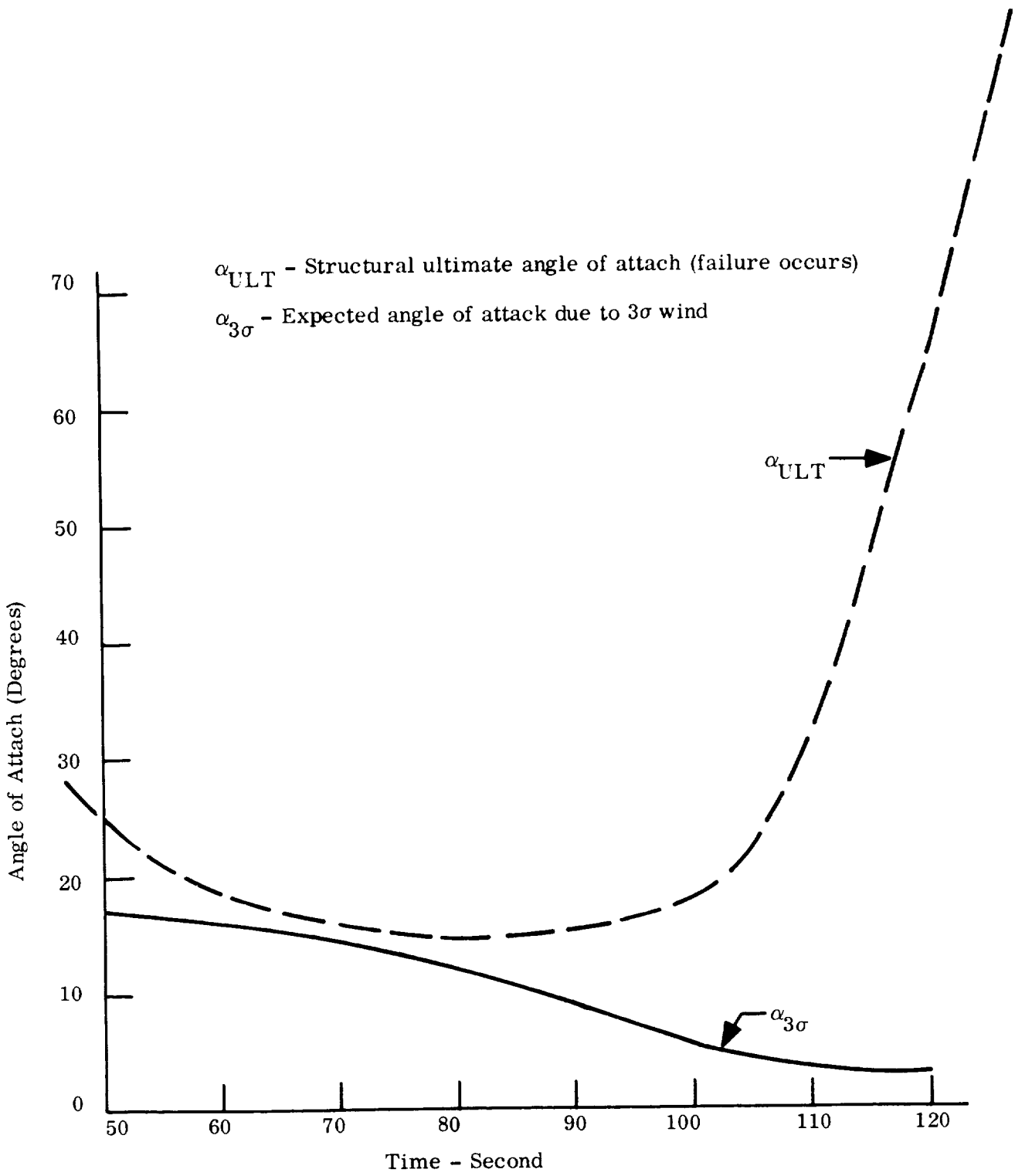



Figure 4-17. MERCURY-REDSTONE Comparison of Angle of Attack versus Time

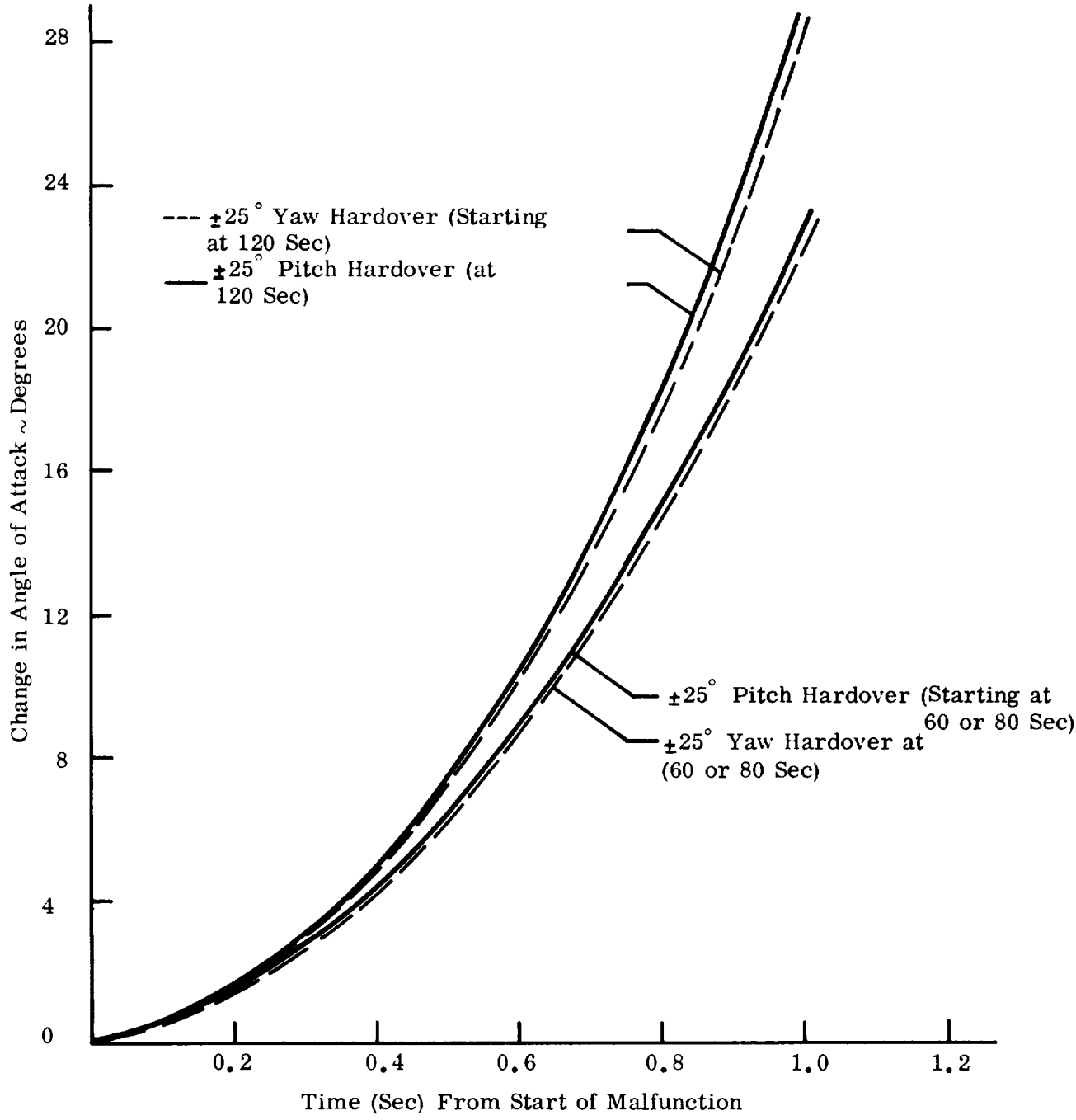



Figure 4-18. Effects of Pitch and Yaw Hardover on Vehicle Angle of Attack (As a Function of Flight Time)

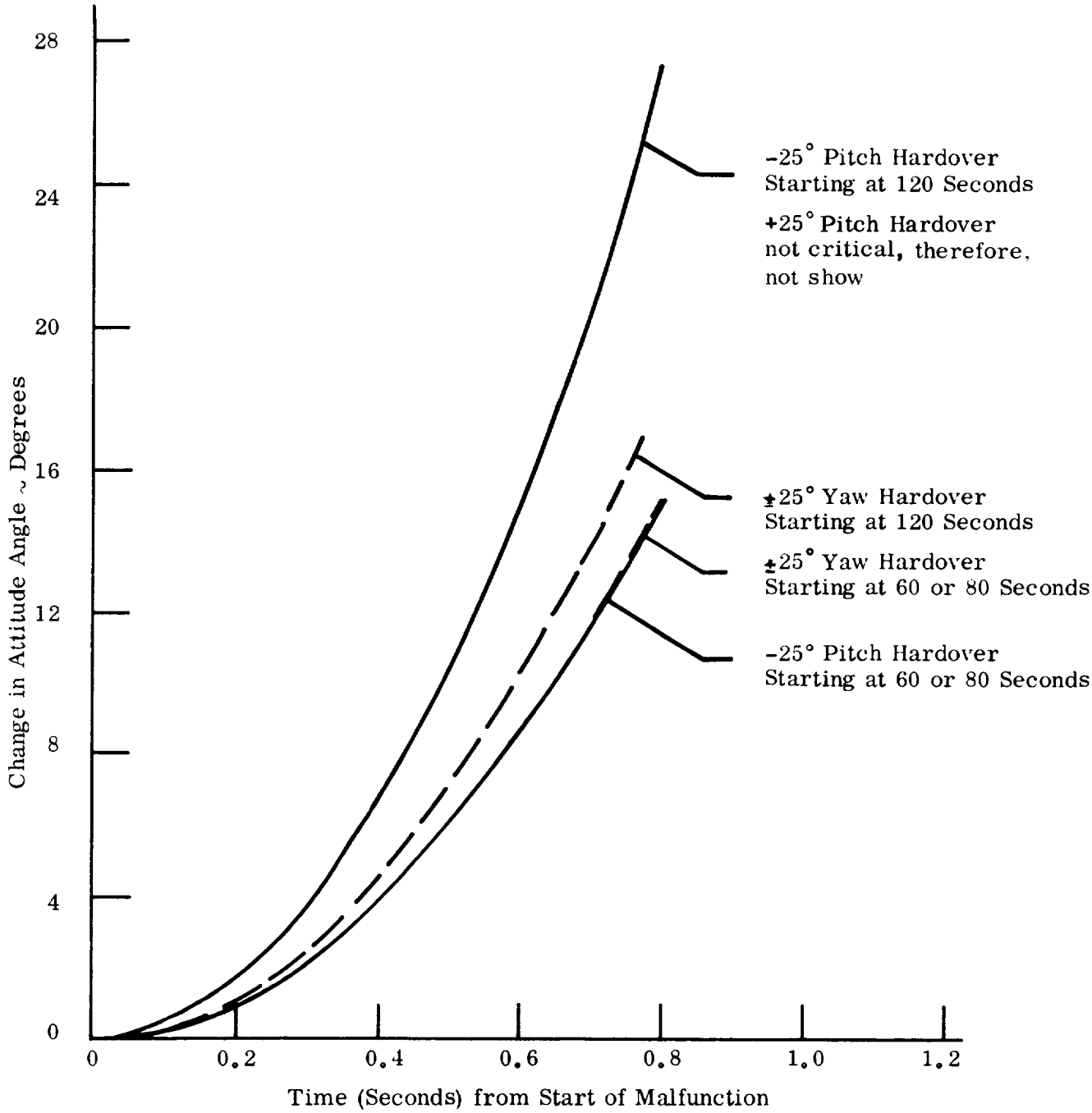



Figure 4-19. MERCURY-REDSTONE Effects of Yaw and Pitch Hardover on Vehicle Attitude Angle (As a Function of Flight Time)

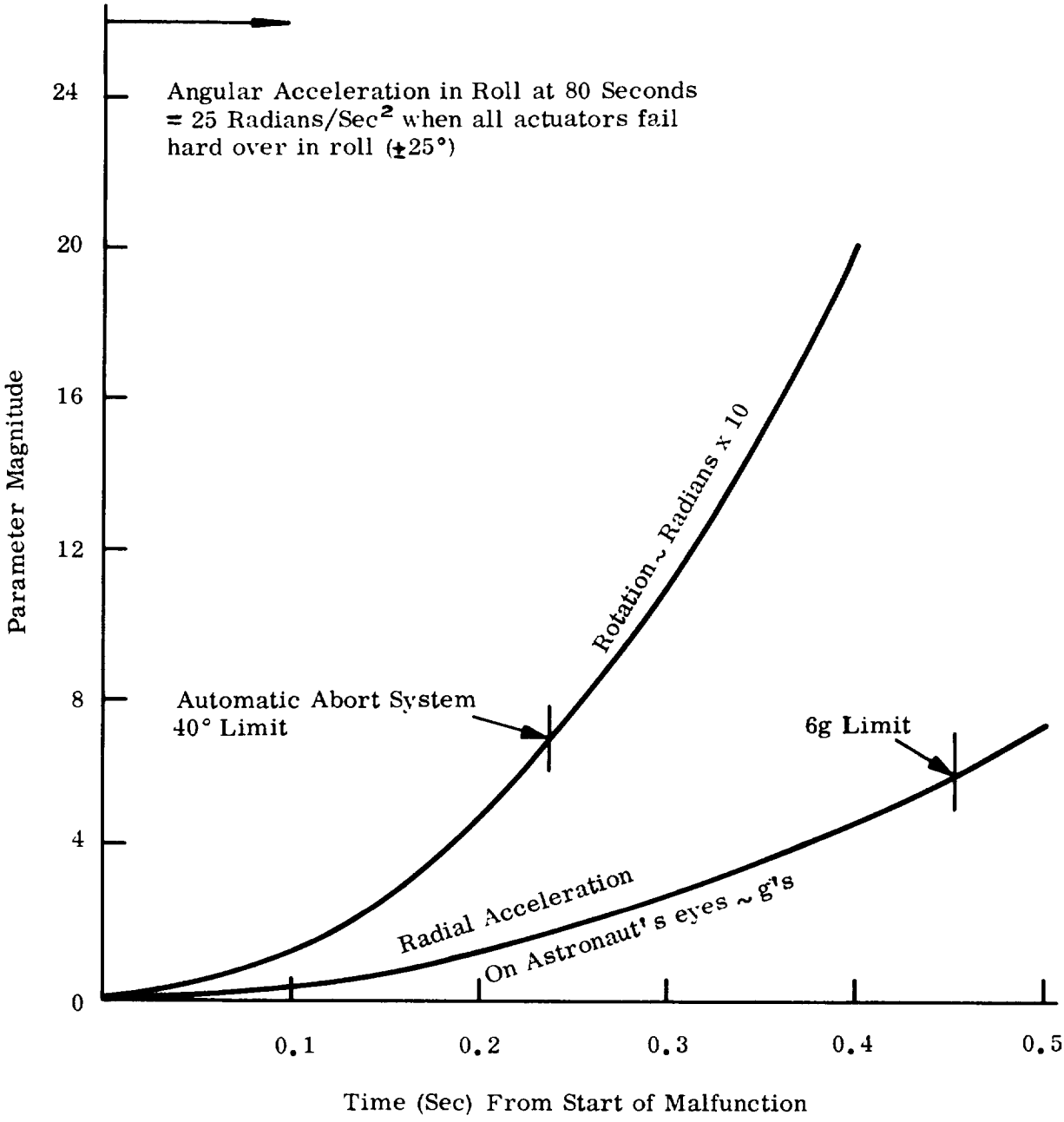



Figure 4-20. MERCURY-REDSTONE Effect of Roll Hardover at 80 Second Flight Time (Worst Case)

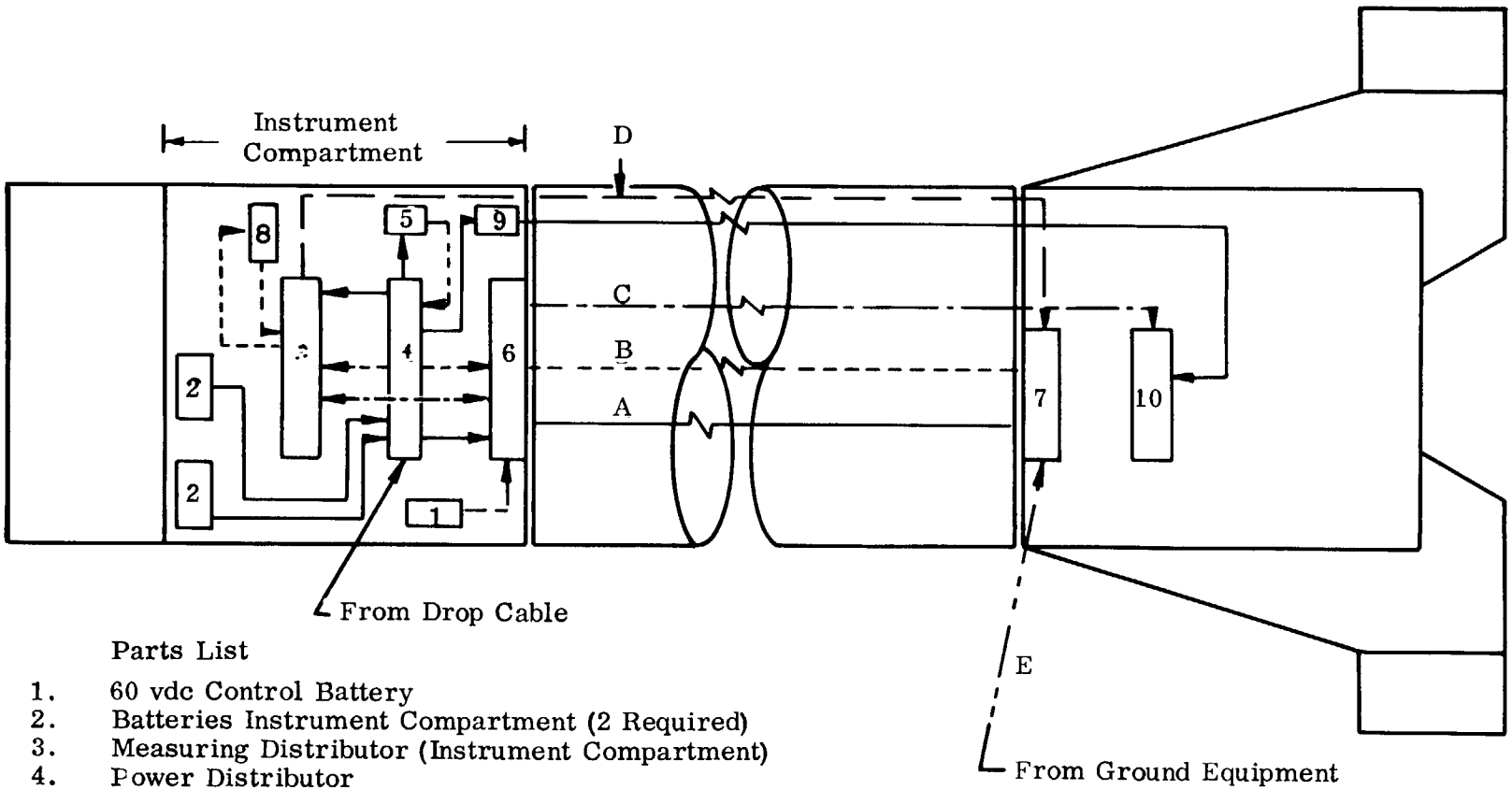
## 4.5 ELECTRICAL POWER NETWORK

The electrical system of the MERCURY-REDSTONE was comprised of a general operational network and a measuring network. The components of the system were contained in the pressurized, temperature-preconditioned instrument compartment in the middle of the aft unit, except for the servo terminal box and the tail distributor which were in the tail unit. A cable conduit running through both propellant tanks connected the power supplies to the terminal box and distributor. Power requirements and supplies are listed below in Table 4-1. Electrical power distribution is shown diagrammatically in Figure 4-21.

Table 4-1

Electrical Power Supplies

| Power Type | Source | Equipment Powered |
|---|---|---|
| 28 vdc | One 1850 amp-minute battery at 10 Minute rate. Zinc-Silver oxide; 72 hour standby life | Control Actuators, One Destruct Command Receiver |
| 28 vdc | One 2650 amp-minute battery at 10 minute rate. Zinc-Silver oxide; 72 hour standby life | General Network Inverter, One Destruct Command Receiver |
| 60 vdc | One 50 amp-minute battery at 10 minute rate. Zinc-Silver oxide; 72 hour standby life | Control Signals |
| 5 vdc | Instrument battery | |
| 115 vac 400 cps | One 1800 volt-ampere inverter and synchronizer | LEV-3 Autopilot, Control Computer, Program Device, AZUSA, DOVAP, Rate Switches, and Measuring System |
| 115 vac 60 cps | Ground Power (nonflight) supplied through 2 connectors in Fin II | Prelaunch: Serving line Strip Heaters, $H_2O_2$ Heating Blanket |




Parts List

1. 60 vdc Control Battery
2. Batteries Instrument Compartment (2 Required)
3. Measuring Distributor (Instrument Compartment)
4. Power Distributor
5. Inverter
6. Main Distributor
7. Tail Distributor
8. 5 vdc Power Supply (Instrument Compartment Measuring)
9. Relay Control Box
10. Servo Terminal Box

Legend

| | |
|---|---|
| A ———— | 28 vdc |
| B - - - - - - - - - - | 115 vac 400 cps |
| C ——— - ——— · — | 60 vdc |
| D — — — — — — | 5 vdc |
| E ——— · - ——— ··· — | 115 vac 60 cps |

Figure 4-21. Electrical Power Distribution

## 4.6 COMMUNICATIONS, TELEMETRY, AND TELEVISION

### 4.6.1 GENERAL

The launch vehicle was equipped with measuring equipment capable of receiving and transmitting information before and during flight. This equipment was located principally in the instrument compartment. The major equipment consisted of:

- 2 Command Receivers and Decoders.
- 1 DOVAP Transponder.
- 1 AZUSA Transponder.
- 1 Telemeter Unit.
- 10 Antennas.

### 4.6.2 COMMAND RECEIVERS AND DECODERS

The command receivers and decoders were the principal components of the command destruct system. The primary purpose of this system was to provide a positive means of engine cutoff and vehicle destruction from the ground. For positive reliability, the system was redundant throughout, sharing only the antennas, the destruct package, and direct connections to these components.

The various command signals were transmitted by frequency modulating (FM), dual-command transmitters (located at the launch site) with selected combinations of audio tones. This FM carrier was received and demodulated by the onboard command receivers. The recovered audio tones were applied to the decoders, which, in turn, energized the proper combination of relays completing the circuitry for execution of the desired command. Reference paragraph 4.7.

### 4.6.3 DOVAP TRANSPONDER

DOVAP (Doppler Velocity and Position) is a long baseline continuous wave system based on the Doppler principle. It is used to determine the instantaneous velocity and position and to predict ballistic trajectory and point of impact.

The broadcast frequency from the launch site was 36.864 mc. Aboard the vehicle, the DOVAP, Model 0, transponder received a signal from the ground station, which had been shifted in frequency due to the vehicle motion. The signal frequency was doubled and retransmitted to the ground stations. Receiving stations and the transmitting station, being in a known geometrical configuration, allowed for accurate determination of trajectory coordinates.

### 4.6.4 AZUSA TRANSPONDER

AZUSA is an automatic, high-precision, all-weather electronic trajectory measuring system based upon the interferometer principle. It was used in trajectory and impact prediction. It consisted of a short baseline ground station tied in with an IBM 709 computer and a vehicle-borne transponder. The MERCURY-REDSTONE carried a Model B, Coherent Carrier AZUSA transponder.

### 4.6.5 TELEMETRY

The MERCURY-REDSTONE telemetering system was a PAM-FM-FM System employing 17 standard subcarrier frequencies modulating a RF carrier of approximately 221.5 megacycles per second. Sixteen channels transmitted information continuously while one channel (channel 15) was commutated at the rate of 10 revolutions per second. The same system had been used successfully in early REDSTONE firings. While the system did not represent the latest development in the state of the art, it is still one of the most reliable systems available. It consisted of a Model XO-2 FM-FM package, a Model 1101 power amplifier, and a power divider.

A total of 41 measurements were made on the launch vehicle in flight. These measurements are listed in Table 4-2. Given are the measurements, their range (if applicable), and a tabulation of the commutated and straight channel assignments for each flight.

### 4.6.6 ANTENNAS

The following is a list of the number and type of antennas installed on the launch vehicle:

- Command — 1 pair, inphase, cavity slot.
- DOVAP — 2 pairs, 180-degree phasing, handlebar type.
- AZUSA — 1 antenna, tapered wave guide.
- Telemetry — 3 antennas, tied together, fed in phase.

Figure 4-22 shows the locations of the antennas.

### 4.6.7 TELEVISION

On MR-2 only, a television camera was installed on the exterior of the instrument compartment. During the boost phase of flight, the camera transmitted pictures of the

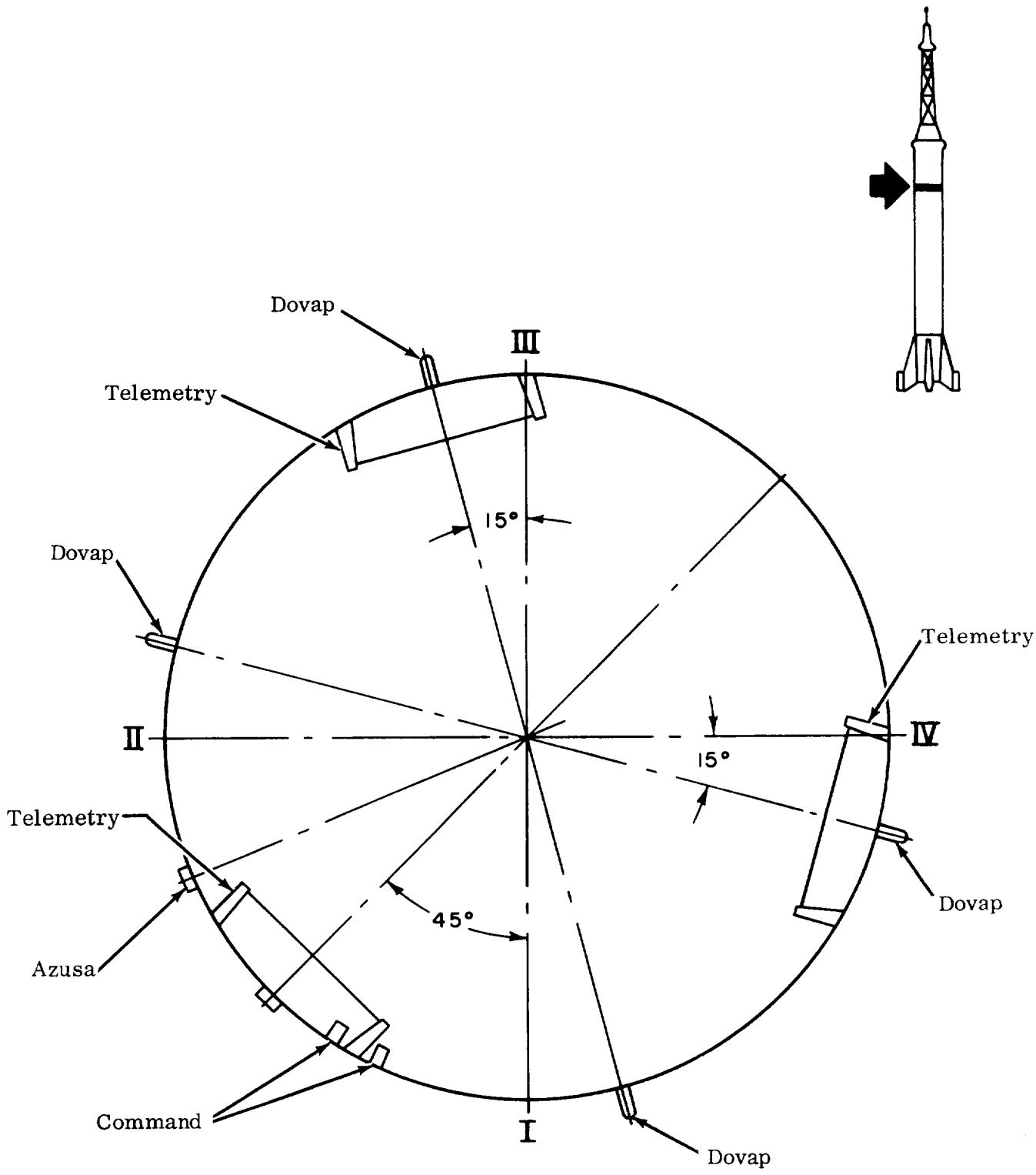



Figure 4-22. Antenna Locations

earth below. The camera was mounted to view upward and slightly inward, thus mirrors were used to reflect the earth's image into the camera lens.

At engine cutoff, the mirrors and their mounting bracket were jettisoned by squib-loaded mechanisms. This permitted the camera to view the separation of the capsule from the booster.

Table 4-2

MERCURY-REDSTONE Booster Flight Telemetry Measurements

| Measurement | Type of Flight Telemetry C = Commutated Channel S = Straight Channel (continuous) | | | | | |
|---|---|---|---|---|---|---|
| | MR-1 | MR-1A | MR-2 | MR-BD | MR-3 | MR-4 |
| Propulsion | | | | | | |
| Pressure in Pressurizing Spheres (0-3500 psi) | C | C | C | C | C | C |
| Pressure in $H_2O_2$ Container (0-700 psi) | C | C | C | C | C | C |
| $H_2O_2$ Valve Position (0-45 degrees) | C | C | C | C | C | C |
| LOX Flow Rate (0-25 gallons per second) | S | S | S | S | S | S |
| Alcohol Flow Rate (0-25 gallons per second) | S | S | S | S | S | S |
| Pressure of Alcohol at Pump Inlet (0-60 psi) | S | S | C | S | S | C |
| Combustion Chamber Pressure (0-400 psia) | C | C | C | S | C | S |
| Error Signal of Thrust Controller (± 5 psia) | | | | C | C | C |
| Combustion Chamber Pressure After Cutoff | S | | | | | |
| Structural Pressure-Vibration-Temperature | | | | | | |
| Instrument Compartment Pressure (0-30 psi) | C | C | C | C | C | C |
| Instrument Compartment Temperature | C | C | C | | | |
| Temperature of AZUSA Transponder Skin | C | | | | | |
| Vibration - Capsule Mounting Ring, Lateral (± 30 g) | S | S | S | S | S | S |
| Vibration - Capsule Mounting Ring - Low Frequency, (Lateral) | | | | S | | |
| Vibration - Instrument Compartment Rate Switch Bracket (longitudinal) | S | S | | | | |
| Vibration - LEV-3 Base Plate (longitudinal) | | | S | S | S | S |

Table 4-2 (Cont)

| | MR-1 | MR-1A | MR-2 | MR-BD | MR-3 | MR-4 |
|---|---|---|---|---|---|---|
| Flight Mechanics | | | | | | |
| Angular Velocity-Pitch (± 10 degrees per second) | S | S | S | S | S | S |
| Angular Velocity - Yaw (± 10 degrees per second) | S | S | S | S | S | S |
| Angular Velocity - Roll (± 10 degrees per second) | C | C | C | C | C | C |
| Longitudinal Acceleration (0 to 6 g) | S | S | S | C | S | S |
| Longitudinal Acceleration (-0.5 to +0.5 g) | S | S | S | C | S | S |
| Speed Pips (from gyro velocity integrator) | S | S | S | S | S | S |
| Vehicle Control | | | | | | |
| Tilt Program, LEV-3 | S | S | S | S | S | S |
| Input to Flight Sequencer | S | S | S | S | S | S |
| Gyro Pitch Position (minus Program) (± 15 degrees) | S | S | S | S | S | S |
| Gyro Yaw Position (± 15 degrees) | S | S | S | S | S | S |
| Gyro Roll Position (± 15 degrees) | C | C | C | C | C | C |
| Deflection - Jet Vane No. 1 (± 15 degrees) | C | C | S | S | C | C |
| Deflection - Jet Vane No. 2 (± 15 degrees) | C | C | C | S | C | C |
| Deflection - Jet Vane No. 3 (± 15 degrees) | C | C | C | C | C | C |
| Deflection - Jet Vane No. 4 (± 15 degrees) | C | C | C | C | C | C |
| Abort System | | | | | | |
| Abort Bus Signal | S | S | S | S | S | S |
| Abort - Attitude Error | S | S | S | C | S | S |
| Abort - Angular Velocity - Pitch (± 5 degrees per second) | S | S | S | C | S | S |
| Abort - Angular Velocity - Yaw (± 5 degrees per second) | S | S | S | C | S | S |
| Abort - Angular Velocity - Roll (± 12 degrees per second) | S | S | S | C | C | C |
| Abort - Control Voltage | S | S | S | C | S | S |
| Abort from Capsule | S | S | S | C | S | S |
| Combustion Pressure Cutoff Switch No. 1 | C | C | C | C | C | C |
| Combustion Pressure Cutoff Switch No. 2 | C | C | C | C | S | S |
| Arm Cutoff to Capsule (on-off) | | C | C | C | C | C |
| Capsule Separation Signal | C | C | C | | C | C |
| Capsule Detached Signal | | | | C | | |

Table 4-2 (Cont)

| | MR-1 | MR-1A | MR-2 | MR-BD | MR-3 | MR-4 |
|---|---|---|---|---|---|---|
| Signals | | | | | | |
| Liftoff | S | S | S | S | S | S |
| Cutoff | S | S | S | S | S | S |
| Emergency Cutoff | C | C | C | C | C | C |
| Command Control Battery Voltage (45-65 vdc) | C | C | C | C | C | C |
| Inverter Voltage (105-130 vac) | | C | C | C | C | C |
| Fuel Dispersion - Safe (5 to 2 1/2 vdc) | C | C | C | C | C | C |
| Fuel Dispersion - Armed (5 to 2 1/2 vdc) | | | | | C | C |

## 4.7 FUEL DISPERSION (DESTRUCT) SYSTEM

The fuel dispersion system (destruct system) consisted of two redundantly connected command receivers, a remote arming unit, and prima cords placed in the propellant tanks.

The remote arming unit employed two separate igniter squibs, each capable of igniting the prima cord. This unit was armed prior to liftoff by the launch personnel. The ignitor squibs would fire upon receipt of an ignition signal from either command receiver. The command receivers fuel dispersion signal was interlocked to assure liftoff, engine shutdown, and a three-second delay for astronaut escape. The engine shutdown interlock was not included in the range safety officer's destruct command circuit.

Sequencing of the destruct and command signals is explained in paragraph 5.1.5. Figure 4-23 illustrates the destruct system.

## 4.8 INITIAL DESIGN CHANGES

### 4.8.1 GENERAL

A basic redesign was necessary to adapt the JUPITER-C to the MERCURY mission. The following changes and additions were made:

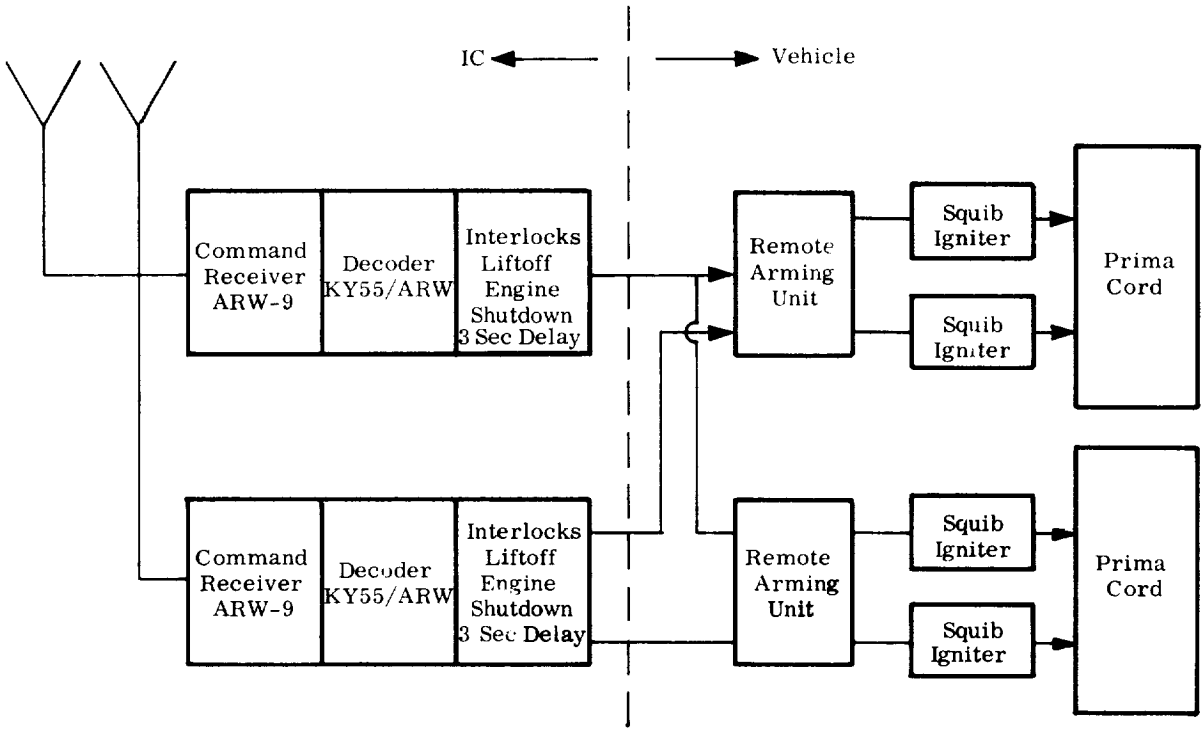



Figure 4-23. Fuel Dispersion (Destruct) System

## 4.8.2 STRUCTURE

### 4.8.2.1 Center Section

To meet performance, the elongated JUPITER-C propellant tanks were used. To handle the increased loads due to the capsule and increased propellants, the tank skin thickness was varied.

### 4.8.2.2 Aft Section

The aft unit and adapter were permanently attached to the center (tank) section. In the military version these had been separated with the payload to provide terminal guidance.

A short capsule adapter including the capsule booster separation clamp ring was supplied by the capsule contractor. This placed responsibility for separation with one contractor.

The aft unit was lengthened 7.08 inches to provide access to the capsule retrorockets.

A fiberglass dish was added in the ballast section initially to protect a booster recovery system and was retained to protect the electronic gear from the heat of the posigrade rockets which fired into the aft section during separation.

A change to increase the reliability of critical electronic components was the pressurization and cooling of the instrument compartment. Layout within this compartment was completely redesigned to accept the new control and abort systems.

Due to its payload and elongated tanks, the MERCURY-REDSTONE became unstable in the supersonic region at approximately 89 seconds after liftoff (refer to Figure 4-10). To partially compensate for this loss of stability, 692 pounds of steel ballast was added forward of the instrument compartment. This was later reduced to 487 pounds during the flight test program as a result of the addition of dampening compound necessary for vibration control.

Because of the extra loads imposed by the increased weight of the MERCURY capsule and propellants, stringers were added to the inner skin structure of the aft unit.

#### 4.8.2.3 Tail Unit

To protect the rotary actuators from the additional heat generated during the longer burning time, stainless steel shields were added to the fins.

A nitrogen gas purge system was added to the tail unit to prevent the accumulation of an explosive mixture in the engine area while on the launch pad.

### 4.8.3 PROPULSION SYSTEM

Nominal burning time was increased to 143.5 seconds, 20 seconds longer than the REDSTONE.

The greater burning time required the addition of a seventh high pressure nitrogen tank for fuel pressurization, and an auxiliary hydrogen peroxide tank to power the engine turbopump.

To prevent major changes midway in the program, the engine was immediately changed from the A-6 to the A-7 model. The A-6 engine was scheduled for replacement and a shortage of hardware would have occurred during the MERCURY-REDSTONE Program.

This early changeover avoided a foreseeable problem area but required an accelerated test program.

A conservative approach was taken with regard to the choice of propellants. The JUPITER-C had used Hydine for greater performance, but its toxicity was considered undesirable for manned flights. In addition, the A-7 engine had never flown with Hydine. Thus for MERCURY-REDSTONE, alcohol was chosen. This selection led to a problem with the vital jet vanes. Alcohol eroded the vanes faster than Hydine and this coupled with the increased erosion of the vanes. Alcohol eroded the vanes faster than Hydine and this coupled with the increased burning time required a selective program to obtain jet vanes of the highest quality

A fuel line bubbling system was added. By bubbling nitrogen gas through the fuel line during the prelaunch countdown fuel freezing was prevented during long holds.

Chamber pressure sensing line heaters were added to eliminate failure due to water vapor freezing in the lines.

The propellant feed subsystem was modified to include a fixed LOX stand pipe and a ground computer for automatic LOX topping during prelaunch activities.

Within the rocket engine system: the pump volute bleed line was removed, the servo valve was modified, the computer assembly was modified, the main fuel and oxidizer valves were shimmed, and the LOX pump wear ring was changed to stainless steel to eliminate sparking (by maintaining proper blade clearances).

O-ring materials were changed in the hydrogen peroxide subsystem to reduce leakage. (Over-aged seals were also replaced.)

### 4.8.4 FLIGHT CONTROL SYSTEM

The ST-80 REDSTONE stabilized platform was eliminated and the guidance system replaced by the LEV-3 autopilot.

### 4.8.5 AUTOMATIC INFLIGHT ABORT SENSING SYSTEM

To assure crew safety, an automatic inflight abort sensing system was added to the booster, and emergency egress operations were incorporated at the launch site. Installation of the automatic inflight abort sensing system sensors required some modification of the other vehicle systems.

### 4.8.6 ELECTRICAL POWER

Changes to the electrical power and distribution network were required to meet the power and signal path requirements of the new equipment. Supporting instrumentation and ground equipment were also modified or changed to match the new and changed vehicle systems.

### 4.8.7 INSTRUMENTATION, COMMUNICATIONS, AND TELEVISION

Major changes were made in the instrumentation system to reflect the changes in the vehicle systems and flight experiments.

Several communication systems were added to provide accurate and redundant telemetry and tracking capability.

A television monitoring system was added to the aft unit to display separation to MERCURY Control personnel.

### 4.8.8 DESTRUCT SYSTEM

The fuel dispersion system was modified to include a three-second delay between command destruct and destruct initiation to permit the capsule sufficient time to separate a safe distance from the booster.

### 4.8.9 GROUND SUPPORT EQUIPMENT

The launch vehicle service structure was modified so that it was remotely controllable, had a semi-clean room at the capsule level, and had a flame deflector and blast shield which protected launch personnel in the event of accidental firing of the escape tower.

Additional air conditioning was added to the blockhouse to offset the heat of the additional electrical test equipment and additional launch personnel.

Additional blockhouse monitoring equipment was installed for the abort system and the $H_2O_2$ steam generator subsystem.

The capability of abort from the pad necessitated the installation of electrical batteries into the ground support equipment to maintain the launch director's abort capability in the event of power failure on the complex. Electronic equipment was added in the control center to receive telemetry indications of the performance of the onboard abort

system, for monitoring purposes. These data were displayed on two recorders in the control center as part of the electrical ground support equipment (refer to Section 7).

An emergency egress system was added.

Other equipments were added as described in Section 7.

## 4.9 LATER MODIFICATIONS

### 4.9.1 GENERAL

During the test programs several problem areas were discovered which required design modifications. These changes occurred as a result of both ground and flight tests. The details concerning the need for the modifications, the methods used to improve the system performance, and the final effects are given in Sections 6 and 8. The listings here are intended for quick reference. Accordingly, the modifications and brief reasons for them are grouped below:

### 4.9.2 MODIFICATIONS RESULTING FROM GROUND TESTS

- An A-7 engine burning instability was discovered at 500 cps. The injections holes were enlarged to overcome this problem.
- Modification of the static test tower removed a low frequency oscillation which occurred during static firing.
- The following components, susceptible to vibrational failure were modified by additional bracketing, remounting, or beefing up:
  a. $H_2O_2$ container bracket.
  b. Engine piping elbow.
  c. Abort rate switch mounting bracket.
  d. Roll rate switch wiring.
  e. Antenna mounting stud.
  f. Fuel vent tubing and poppet valve.
  g. Rate gyro bracket (LEV-3 mounting bracket).

### 4.9.3 MODIFICATIONS RESULTING FROM FLIGHT TESTING

On MR-3, 340 pounds of X306 (lead impregnated epoxy polysulfide dampening compound) was added to the bulkhead and walls of the ballast section. On MR-4 an additional

102 pounds of compound were added (see Figure 4-24). Longitudinal stiffeners were also added to the internal skin surface as follows:

| | |
|---|---|
| Flight MR-BD | 4 stiffeners |
| Flight MR-3 | 14 stiffeners |
| Flight MR-4 | 14 stiffeners |

Prior to MR-BD the $H_2O_2$ pressure regulator was set at 570 psig.

After MR-2 the thrust control servo valve was adjusted to a minimum of 25 percent open for smoother starting.

Excessive pivot torque on the LEV-3 longitudinal integrating accelerometer, used for engine cutoff, was prevented after MR-1A by relocation of 5 of 8 electrical leads and use of softer wire on the remaining three. In addition to this accelerometer, a time-based cutoff at 143 seconds was employed on MR-2 and MR-BD.

Velocity cutoff arming and switching of the $P_c$ switches to the depletion mode (fuel depletion arming) were separated after MR-2; also, velocity cutoff arming was advanced to 131 seconds, and fuel depletion arming was set at 135 seconds.

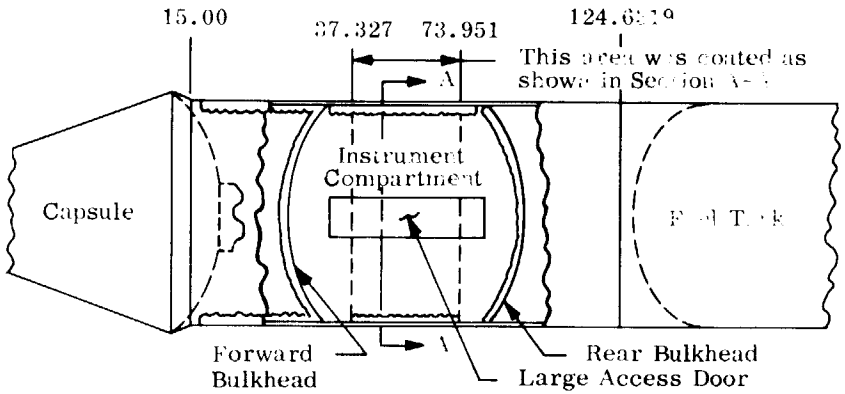
The roll-rate abort sensor was found unnecessary and was deleted after MR-2 to increase mission success.

A network filter was added to the control computer to reduce control loop gain between 6 and 10 cps after MR-2.

After MR-1, a one foot ground strap was added and the Fin II connector mounting modified (see Figure 4-25).

The vibration pickup was moved from the rate switch bracket to LEV-3 baseplate after MR-1A for the remaining flights.

For Flight MR-BD two jet vane deflections, one low frequency vibration transducer, and one engine chamber pressure measurement were telemetered via straight channels. An "Arm Cutoff to Capsule" switch was added to the blockhouse propulsion panel after MR-1.

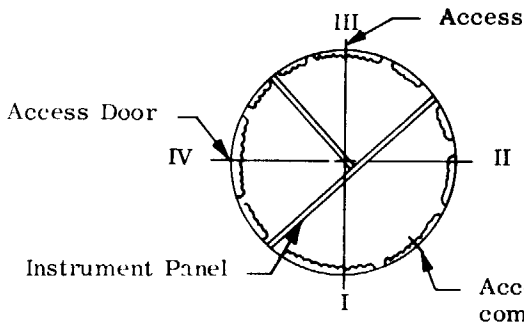



MERCURY-REDSTONE MR-4

Indicates Installation of X306 Dampening Compound

Notes:

1. The dampening compound shown to the rear of the forward bulkhead is unique to the MR-4 booster.
2. All compound shown forward of the forward bulkhead (including that on the bulkhead) was also on MR-3.
3. Arrangement of stiffeners (14 total) was same as MR-3.




Section A-A

Figure 4-24. Installation of Dampening Compound in Instrument Compartment and Adapter Section

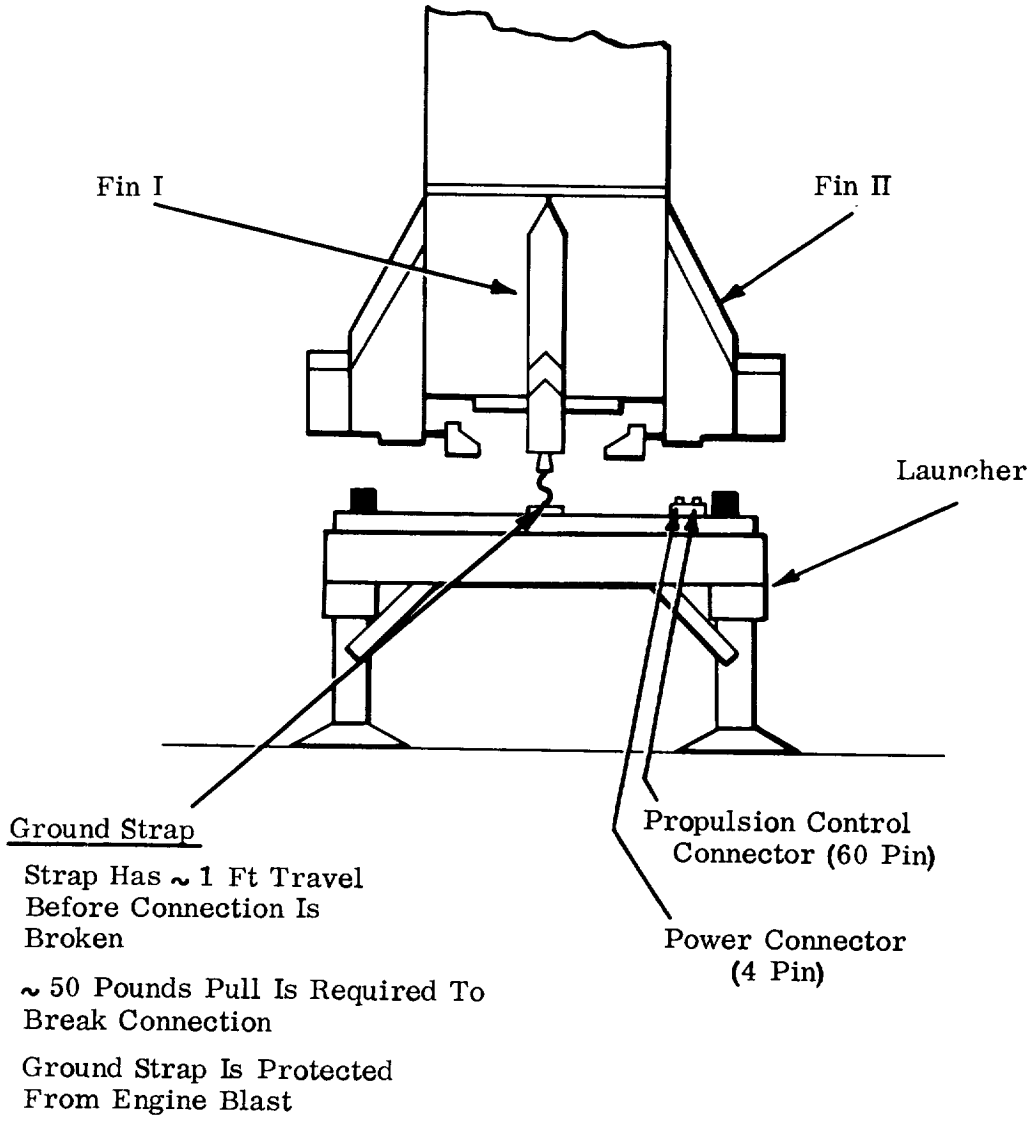



Figure 4-25. Ground Strap Function Just After Liftoff

# SECTION 5

# MAN-RATING

## 5.1 INTRODUCTION

The man-rating program for the MERCURY-REDSTONE was planned to achieve the highest possible crew safety by providing abort capability from the time of astronaut boarding through capsule separation. This safety was further increased by quality and reliability assurance programs designed to improve the mission reliability of the basic vehicle. The success of the man-rating programs was not only demonstrated by perfect vehicle operation during the two suborbital flights, but also by the proper monitoring of the abort sensing system during each of these flights.

The MERCURY Program was initiated at a time when the REDSTONE booster had been well developed and had an established reliability. This reliability, which was high for a tactical missile (see Section 2), was still considered insufficient for manned flight. To redesign for the required assurance could have meant a totally new program and a lower reliability; therefore, the man-rating program was based on increasing the astronaut's safety by adding an abort system and making only those vehicle changes necessitated by mission requirements.

In January 1959, the Army Ballistic Missile Agency (ABMA) received the go ahead for missile adaptation. The following March, the Space Task Group (STG) requested ABMA to design an abort system. During May and June, coordination meetings were held between STG, ABMA, and the McDonnell Aircraft Company. In June 1959, ABMA submitted an abort system proposal. The abort system was to be installed on all flights with only the first flight to be "open loop," thus obtaining the greatest amount of full system testing possible. During 1959 and 1960, additional quality control and test procedures were phased in as permitted by the launch schedule.

## 5.2 AUTOMATIC INFLIGHT ABORT SENSING SYSTEM

### 5.2.1 GENERAL

The automatic inflight abort sensing system was developed to detect vehicle malfunctions which could lead to a compromise of the astronaut's safety. If such a malfunction was sensed, the abort system would shutdown the booster engine and send an abort

signal to the capsule. This signal activated the escape system through the MAYDAY relays. The abort sensing systems thus, had to be compatible with the vehicle, the capsule interface, and the modes of flight operation. A block diagram of the system is shown in Figure 5-1.

### 5.2.2 SYSTEM CRITERIA

Crew safety required immediate and decisive action in the event an emergency condition developed. The abort action had to prevent the emergency condition from becoming a catastrophe, i.e., a condition which gravely endangered the life of the astronaut. An automatic abort sensing and implementation system was selected since some emergency conditions could develop too rapidly to permit manual activation of abort. In addition, an automatic system would relieve an astronaut, whose performance under flight loads was not well established, from the requirement to monitor and sense all emergency situations.

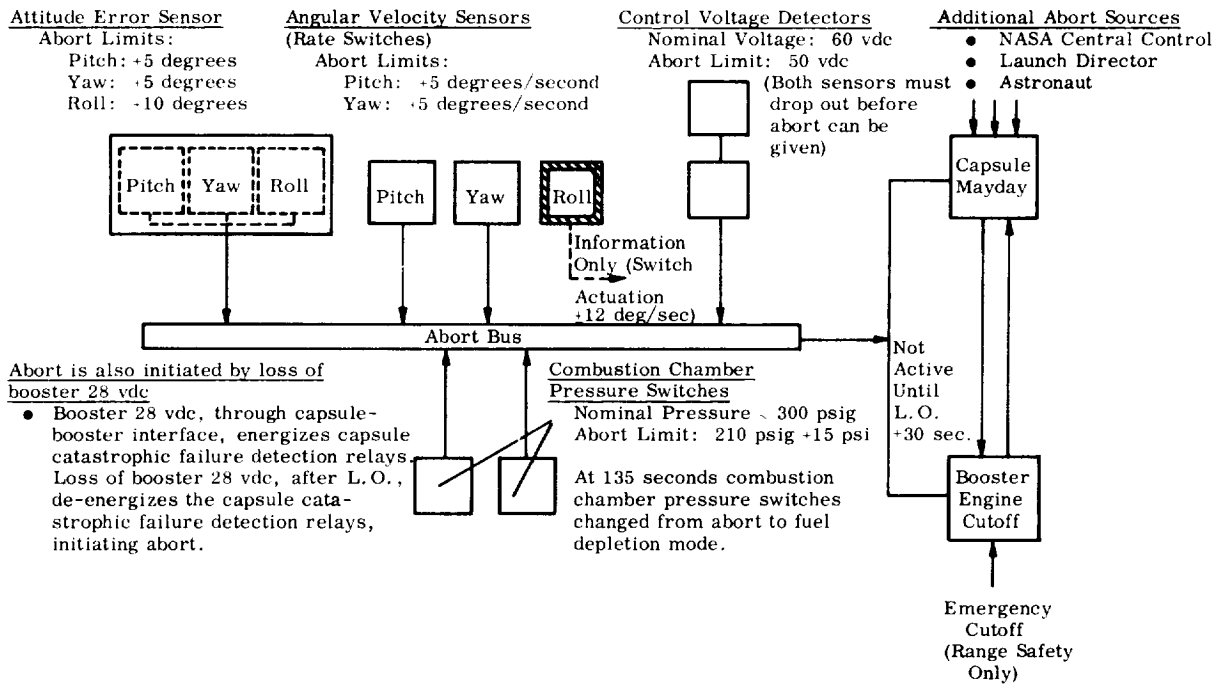
### 5.2.3 SYSTEM GUIDELINES

The guidelines for the development of this system were as follows:

- The abort sensing system shall be tailored to the critical performance parameters of the launch vehicle.
- The abort sensing system components shall be located on the launch vehicle and one signal sent to the capsule.
- The abort signal shall be given as soon as possible after an emergency condition exists.
- The system shall be activated at liftoff and completely deactivated at engine cutoff.

The guidelines for system design were as follows:

- Existing launch vehicle hardware, for sensing signals, shall be utilized wherever possible.
- Parameters shall be sensed which most easily and reliably monitor the greatest possible number of malfunctions.
- Electrical power for the sensors shall be taken from the launch vehicle's normal ac and dc supply systems. Loss of power shall be an abort condition.
- GSE monitoring shall be required.
- Sensor and system performance shall be telemetered in flight.
- Switching of sensors or sensor limits during flight shall be minimized or eliminated.




Abort System Telemetered Information

- Abort Bus Signal
- Attitude Error Abort Signal
- Rate Switch Abort Signals (Pitch and Yaw)
- Control Voltage Detector Abort Signal
- Combustion Chamber Pressure Abort Signal No. 1
- Combustion Chamber Pressure Abort Signal No. 2
- Abort Signal from Capsule

Notes:

- The booster automatic abort system becomes active at lift-off.
- At normal booster engine cutoff the capsule will no longer accept a booster abort signal.
- Prior to lift-off the abort bus and booster abort sensors are at all times supervised in the ground support equipment.

Figure 5-1. Block Diagram of MERCURY-REDSTONE Automatic Inflight Abort Sensing System

The guidelines for hardware design were as follows:

- Flight-proven equipment shall be used to the greatest extent possible.
- All equipment shall be subjected to a thorough qualification test program.
- All components of the abort sensing system shall be subjected to a thorough reliability test program.

### 5.2.4 MALFUNCTION AND PERFORMANCE STUDIES

Prior to selecting the abort parameters, a failure mode analysis was made of 60 REDSTONE tactical missile flights to determine the best choice of malfunction sensors (Table 5-1). The study included a large number of components which had failed or could conceivably fail and found that sensing each component and mode of failure was both impracticable and degrading to operational reliability. However, the study did indicate that many malfunctions led to identical results, thus permitting the use of only a few basic types of sensors. The parameter sensors and limits selected are given in Table 5-2.

To determine the abort limits in attitude and angular rates, probability studies were made based on REDSTONE performance. The results, tabulated in Table 5-3, led to the final selection of the abort limits. The chamber pressure limits for abort were established by a study of the thrust buildup and normal fluctuations, (Figure 5-2). The electrical voltage limit was set just above the minimum required to operate the missile electrical systems.

### 5.2.5 ABORT SENSING RELIABILITY

#### 5.2.5.1 General

With the addition of an abort sensing system to the launch vehicle, mission reliability is decreased due to the probability of a false abort signal curtailing an otherwise successful mission. Redundancy was used in the sensing system in order to overcome this potential problem (which could also subject the astronaut to unnecessary hazards) and also to reduce the probability of failing to detect an actual emergency condition. The following paragraphs describe specifically how redundancy of parameters and sensors was employed to improve the probability of detecting an actual abort condition and to reject a false abort signal.

Table 5-1

Flight Failure Analysis of REDSTONE Propulsion System

| Mode of Failure | Probable Cause | Corrective Action |
|---|---|---|
| 1. Rough combustion | Dry and slow start. | Full flow LOX and water lead start was employed. |
| 2. Gas generator system performance drop. | a. $H_2O_2$ tank pressure regulator failure.<br>b. $H_2O_2$ depletion.<br>c. Vortex in $H_2O_2$ tank. | a. Improved pressure regulator (8073214) was employed.<br>b. Adequate $H_2O_2$ was provided.<br>c. Anti-vortex baffles were employed in the $H_2O_2$ tanks. |
| 3. LOX container pressure decay. | LOX vent valve failure. | Valve bearings were redesigned to lower friction. |
| 4. LOX depletion (cutoff earlier than predicted) | High LOX flow, and preliminary data used in flight prediction analysis. | Reliable test data became available and were used in MR flight prediction analysis. |
| 5. Rapid decline in combustion chamber pressure and turbine RPM. | Increased pressure drop across the gas generator system during flight. | Gas generators on all engines were inspected for proper loading. Static firing of the boosters included operation from nominal to high and then to low thrust levels in 10 steps. |
| 6. Thrust control system improper operation. | a. Water froze in pressure transducer sensing line.<br>b. Improper servo valve calibration. | a. Strip heaters were installed on pressure transducer sensing lines to maintain temperature above freezing.<br>b. Interchange of servo valves was not allowed. Replacement limited to use of recalibrated spare only. |
| 7. Thrust control system inoperative | Servo valve electrical cable not connected (human error). | Electrical cable to servo valve disconnect was not permitted during checkout on MR vehicles. |
| 8. Low missile acceleration on ascent. | Improper calibration of propellant flow (human error). | Reliable test data became available and were used in MR calibrations. |

Table 5-1

Flight Failure Analysis of REDSTONE Propulsion System (Cont.)

| Mode of Failure | Probable Cause | Corrective Action |
|---|---|---|
| 9. Cutoff velocity, flight time, and range greater than predicted. | Same as 8. | Same as 8. |
| 10. Fuel depletion (cutoff earlier than predicted). | Insufficient amount of fuel on board at liftoff. | Recording flowmeter was employed during tanking. |
| A review of the REDSTONE propulsion system inflight malfunction and performance deviations was conducted to ascertain that necessary actions were taken to correct the possible deficiencies of the MERCURY-REDSTONE booster.<br><br>Note: Failure 1 and 3, which occurred during flight tests of earlier REDSTONE missiles, resulted in unsuccessful accomplishment of the booster and missile mission. The other 8 failures were less serious and permitted the boosters to complete their missions. | | |

Table 5-2

MERCURY-REDSTONE Abort Parameters

| Parameter | Sensor | Limit and Tolerance |
|---|---|---|
| Vehicle Attitude | Attitude Error Sensor | |
| Pitch | Pitch | 5 degrees, +1 degree -0 degree |
| Yaw | Yaw | 5 degrees, +1 degree -0 degree |
| Roll | Roll | 10 degrees, +2 degree -0 degree |
| Vehicle Angular Velocity | Pitch Rate Switch | $\pm$5, +0.3, -0 degree per second |
| | Yaw Rate Switch | $\pm$5, +0.3, -0 degree per second |
| Engine Combustion Chamber Pressure | Pressure Switch | 210 $\pm$15 psig |
| 60 vdc Control Power Supply | Control Voltage Detector | 50 $\pm$2 vdc |
| 28 vdc General Network Power | Capsule-Launch Vehicle Interface Connector | Loss of voltage if connector opened |

Table 5-3

REDSTONE Attitude Angles and Rates During
A Normal Ballistic Trajectory

| Predicted Maximums | | | |
|---|---|---|---|
| Item | Probability less than 0.155 at 95 percent confidence* | Probability less than 0.058 at 95 percent confidence* | Probability less than 0.028 at 95 percent confidence* |
| Attitude Angles (degrees) | | | |
| Pitch | 2.3 | 2.9 | 3.3 |
| Yaw | 3.9 | 5.0 | 5.8 |
| Roll | 3.1 | 4.0 | 4.7 |
| Attitude Rates (degrees per second) | | | |
| Pitch | 3.2 | 4.0 | 4.7 |
| Yaw | 2.0 | 2.5 | 2.9 |
| Roll | 7.0 | 9.25 | 11.2 |

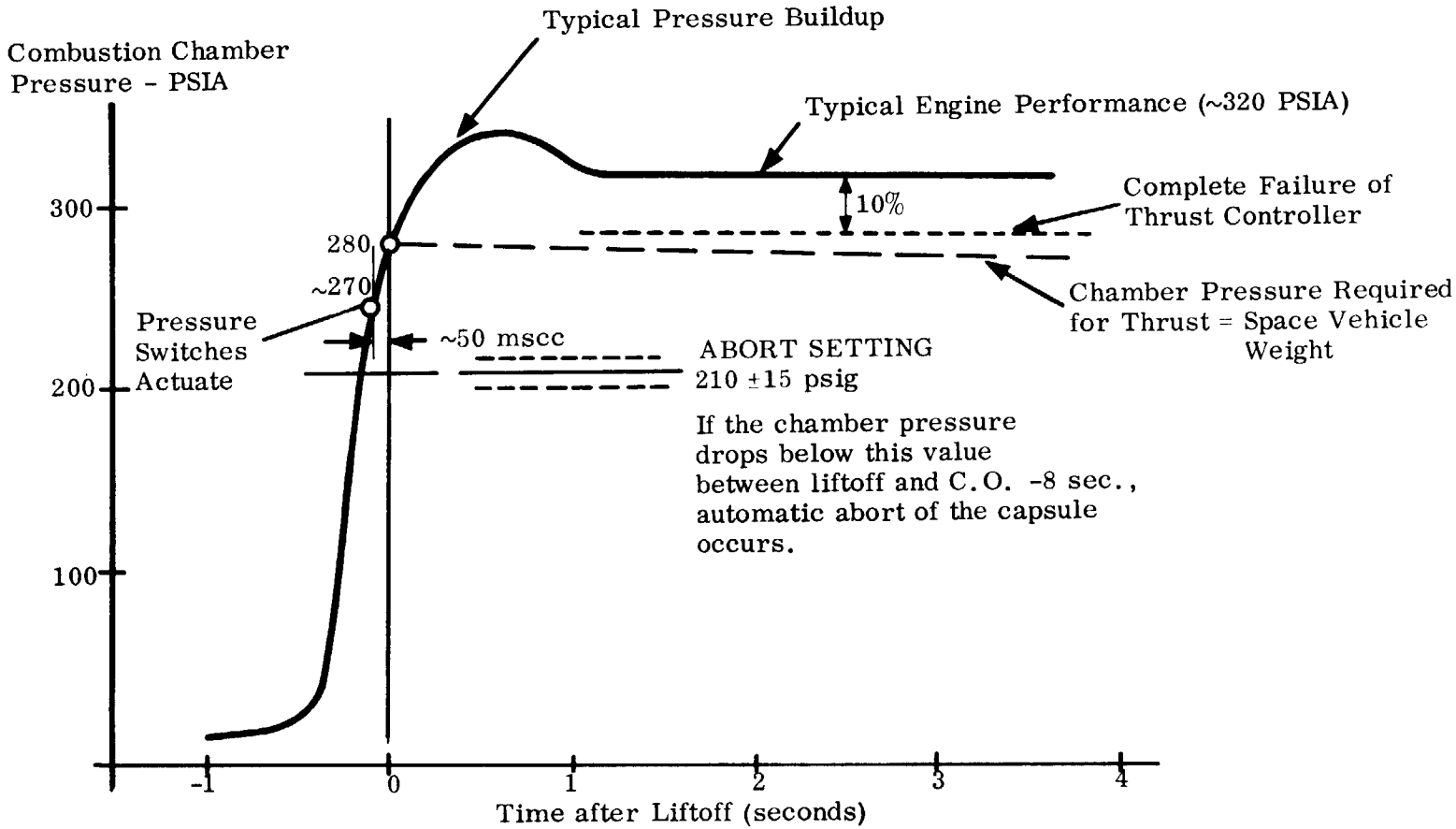
* Probability calculated from flight test data of 50 previous REDSTONE and JUPITER-C launches.

5.2.5.2 Detection of an Actual Vehicle Malfunction

If a particular sensor failed, redundancy in the system would enable the malfunction to be detected either by sensors of related vehicle performance parameters or by redundancy in the design of the sensor itself.

Attitude Error Sensor and Rate Switches

If an attitude error sensor failed and control failure in that vehicle axis developed, the vehicle deviations would have been sensed by the rate switch in that axis. Also, since such an indication was normally not limited to one axis, the sensors in the other axes would also signal abort.




Note: Pressure switches are switched out of abort system at C.O. -8 seconds by Program Device.

Figure 5-2. Thrust Buildup

- Control Voltage Detectors

  If the 60 volt dc control voltage was lost, and the control voltage detectors which sensed it failed, the LEV-3 attitude pickoffs would not have been able to sense vehicle attitude deviations and the vehicle would have gone out of control. In this case, the rate switches would still have been in operation since they were powered by the 400 cps power source.

- Combustion Chamber Pressure Switches.

  Parallel switches were employed to assure engine monitoring in the event one pressure sensor failed.

5.2.5.3 Prevention of a False Abort Signal

A false abort command from a failed abort sensor precludes successful mission completion and subjects the astronaut to the hazards of high acceleration flight loads, aerodynamic buffetting and rescue from an off-nominal recovery area. In order to prevent abort from a sensor failure, the following provisions were made:

- Attitude Error Sensor

  Since a certain voltage level from an attitude pickoff of the LEV-3 had to be supplied for operation of this sensor, a loss of this voltage would have made the sensor inoperative, and an abort signal would not have been given.

- Rate Switches

  A mechanical spring kept the switch arm in the zero rate position. Closing of the switch contacts was possible only if the motor was running and the rate switch was turning around its sensitive axis at a rate above the set limits.

- Control Voltage Detectors

  Two control voltage detectors were used in series and both would have had to indicate a voltage drop to a preset value before abort would have been initiated.

- Combustion Chamber Pressure Switches

  When the combustion chamber pressure increased at mainstage engine ignition, the switches opened, actuated lock-in relays, and place the parallel pressure switches in the abort circuit. This lock-in feature prevented giving an abort signal if the switches did not open during thrust buildup and permitted ground monitoring of them up to liftoff.

Capsule-Launch Vehicle Electrical Interface

The Capsule-launch vehicle interface provided the means for the launch vehicle's 29 vdc to energize the capsule catastrophic failure detection relays. Loss of this voltage after liftoff would have initiated an abort signal. Two physically separate electrical interfaces were provided in order to prevent a false abort signal due to an interface wire connection break.

### 5.2.6 ABORT SIGNAL INITIATION AND SEQUENCING

The over-all system was designed to initiate abort signal:

By wire link before liftoff.
By radio link before and after liftoff.
By manual (astronaut) initiation after capsule umbilical drop.
By the launch vehicle inflight abort sensing system after liftoff.

These modes of abort initiation and the time sequencing used are shown in Figure 5-3 through 5-6.

As indicated in the figures, range safety considerations determined a major step in the sequencing. If an abort was required early in the flight (before T+30 seconds), the booster might have fallen on land if the abort signal was permitted to shutdown the engine in the normal manner. Thus, initiation of engine shutdown was limited to the Range Safety Officer during that period.

### 5.2.7 NETWORK AND SENSOR DESCRIPTIONS

#### 5.2.7.1 Abort Network

The MERCURY-REDSTONE abort sensing network is shown in the preflight and inflight modes, Figures 5-7 and 5-8 respectively. The network consisted of three functional circuits: the Abort Bus (input signals), the Abort Relay (abort output signal), and the Engine Cutoff circuitry.

Abort Bus

The abort signals from all automatic sensors were connected to an abort bus. This bus would signal abort only through the abort relays (K7-1, -2, -3, and -4) after liftoff. Prior to liftoff abort command was sent to the capsule abort relays via hardwire, and the abort

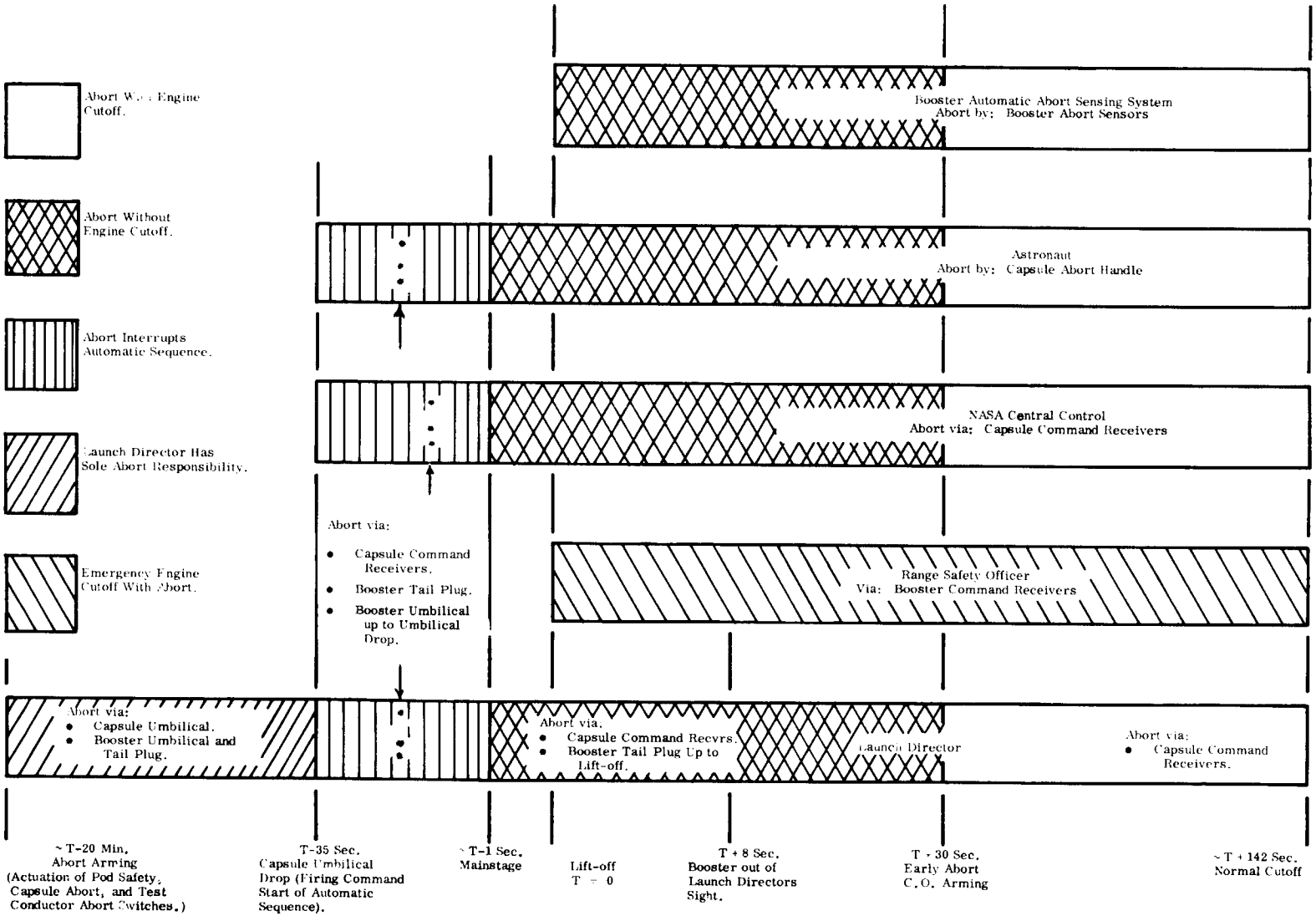



Figure 5-3. Abort Responsibility Assignments versus Time for Manned MERCURY-REDSTONE Mission

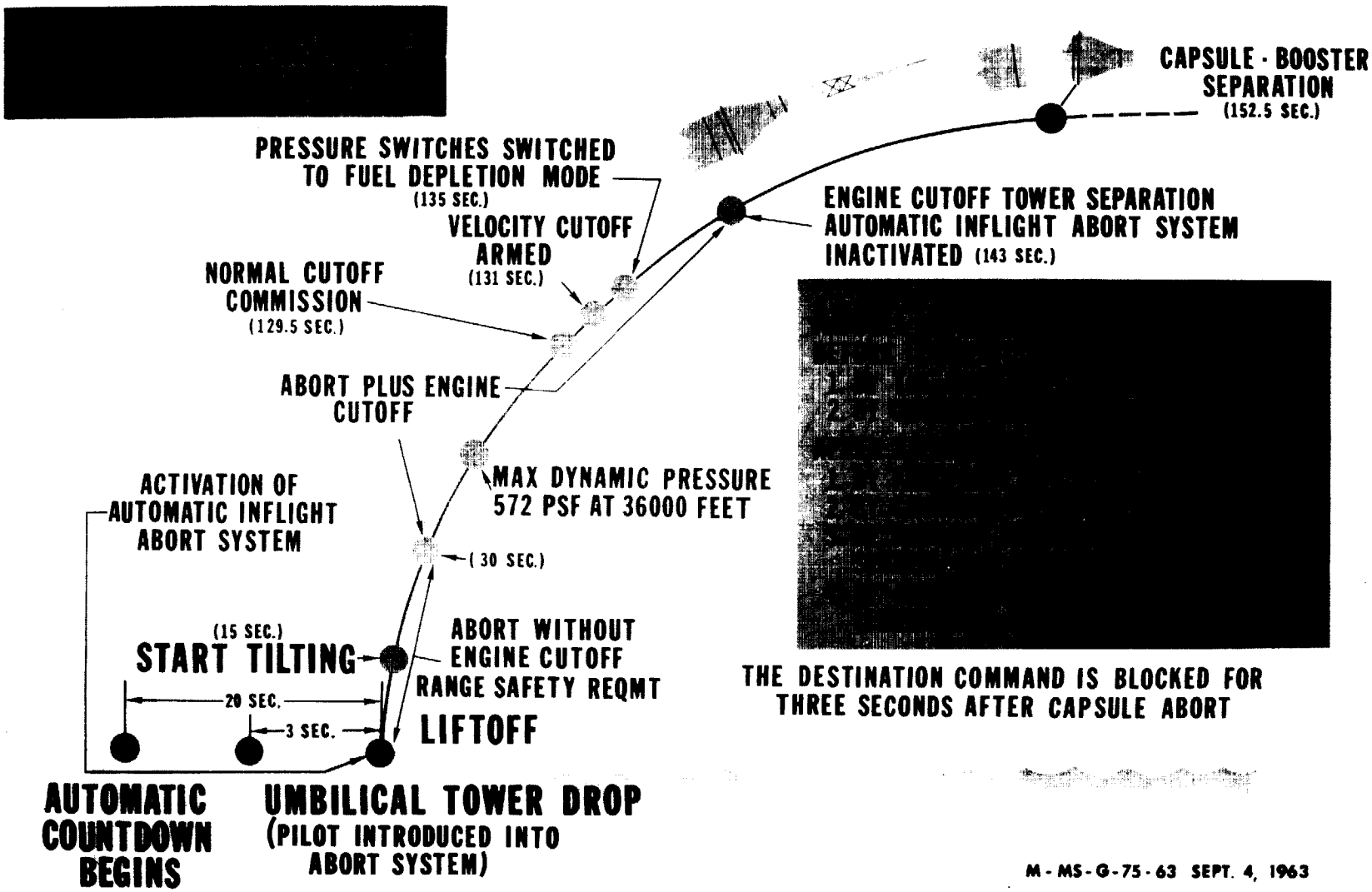



Figure 5-4. MERCURY-REDSTONE Booster Flight

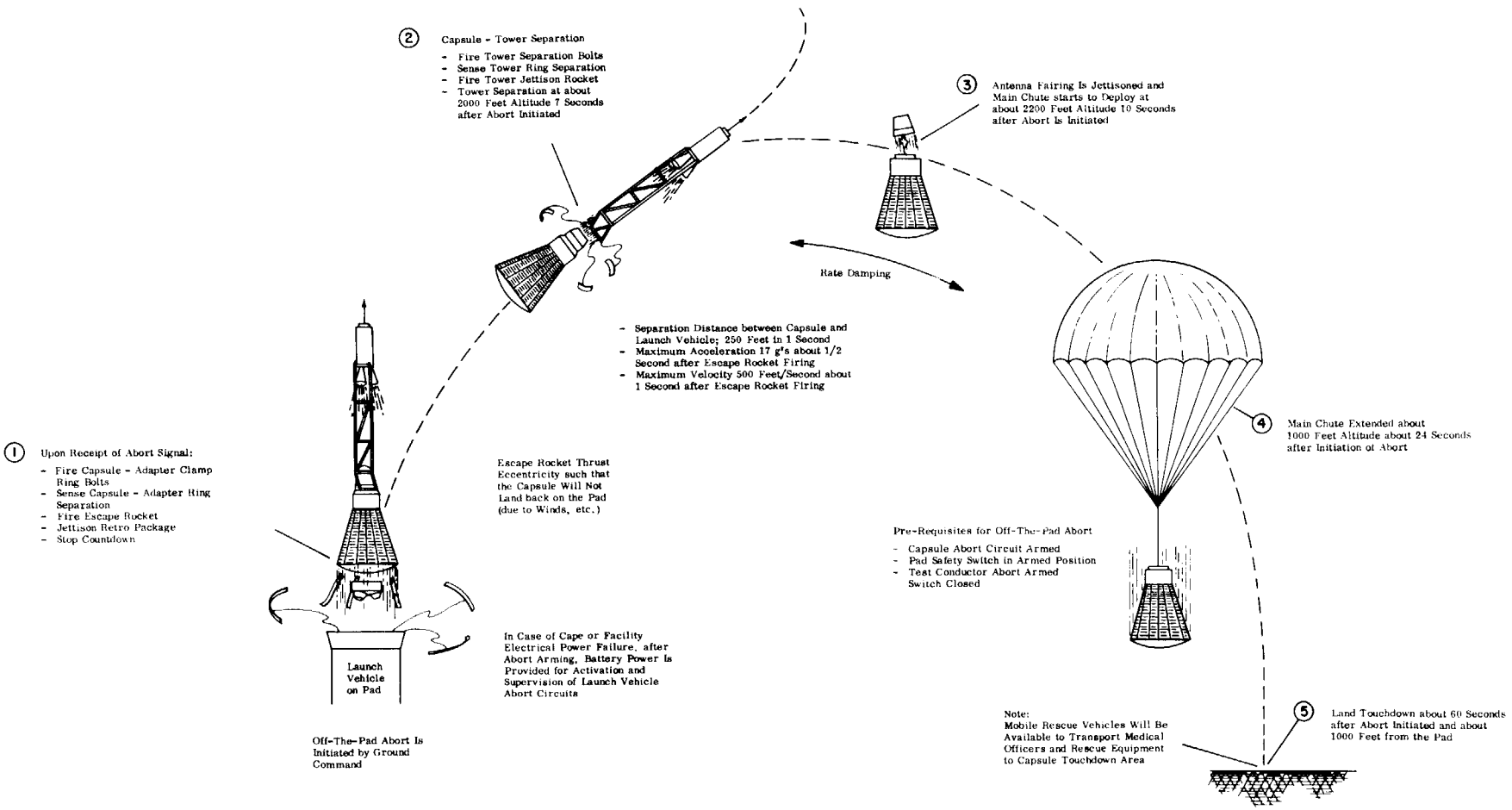



Figure 5-5. Off-The-Pad Abort

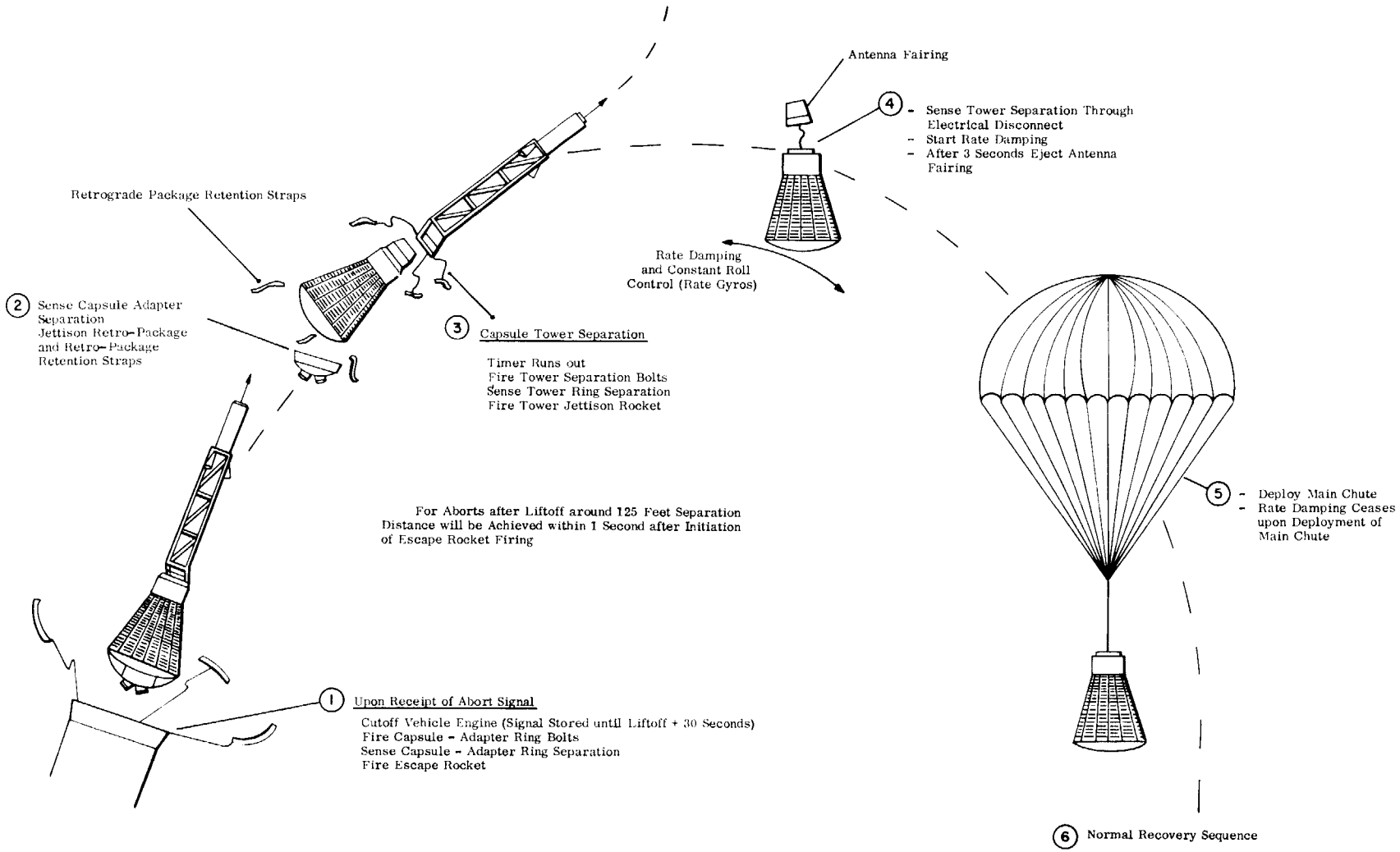



Figure 5-6. Abort After Liftoff up to Normal Engine Cutoff

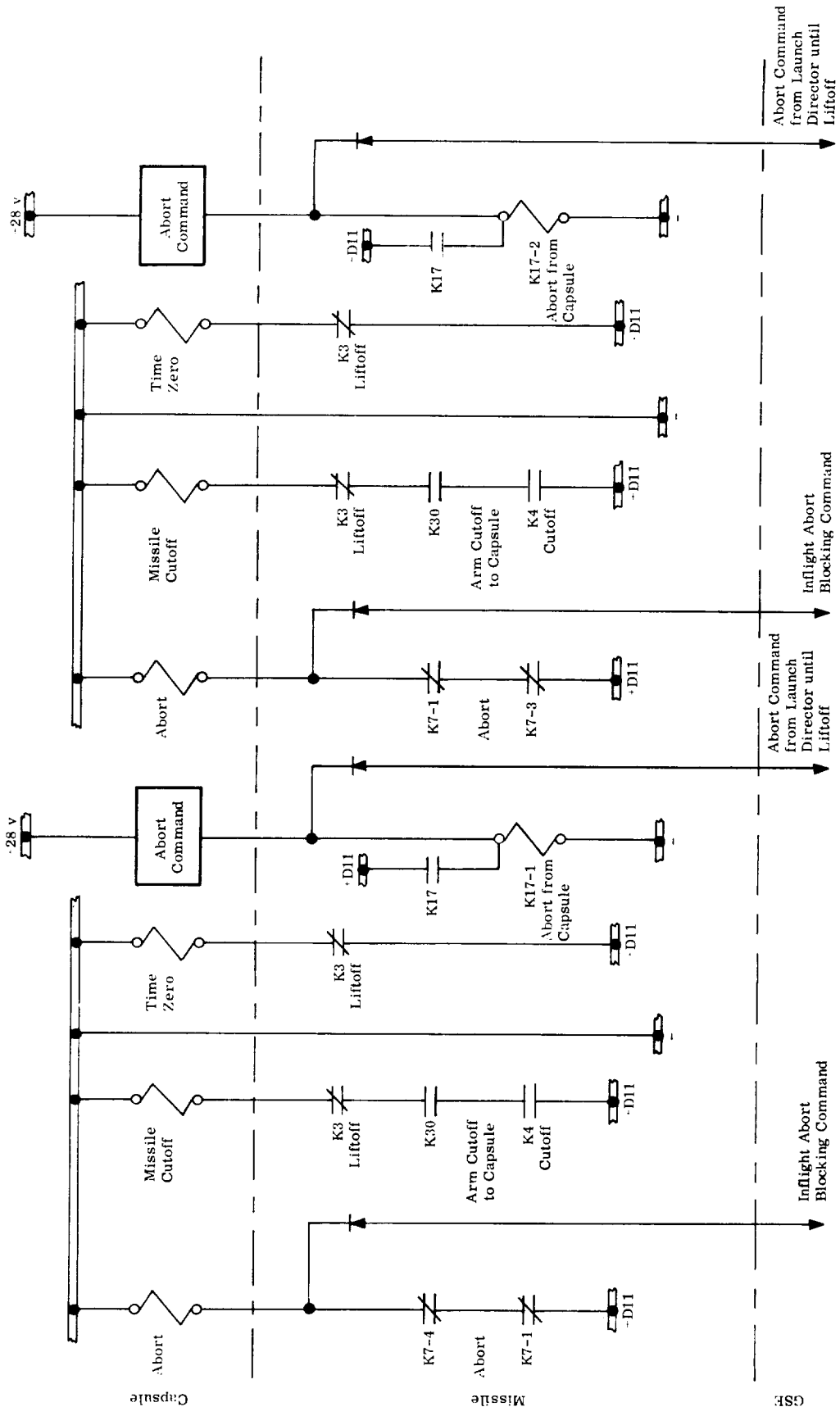



Figure 5-7. Preflight Abort Network Schematic Diagram

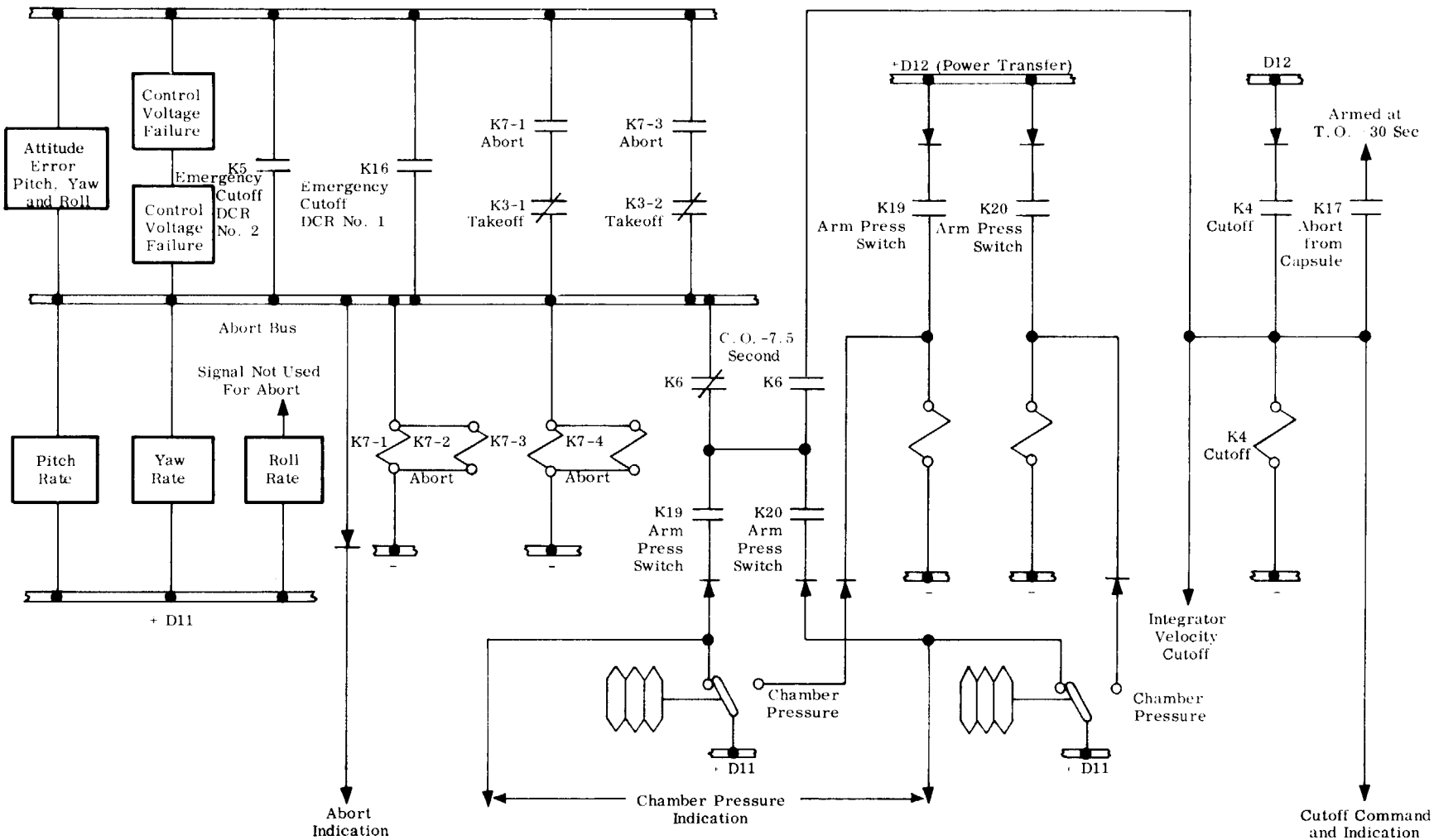



Figure 5-8. Inflight Abort Network Schematic Diagram

bus was monitored by ground support equipment. For safety and as a final check, the launch sequence was blocked if an abort condition existed in the automatic system prior to liftoff.

a. Attitude Error Sensor

This device monitored the output of the gyro system in pitch, yaw, and roll. If any of the attitude angles exceeded the specified limit, a signal was sent to the abort bus.

b. Rate Switches

The three rate switches were mounted in the pitch, yaw, and roll axes. If excessive angular movements occurred in the pitch and yaw axes, a signal was given to the abort bus. The roll rate signal was only monitored by telemetry and did not have energize the abort bus.

c. Control Voltage Detector

If the 60-volt control voltage supply dropped below 50 volts, the voltage sensors gave a signal to the abort bus. Two sensors were used and both had to indicate failure before the abort signal could pass to the abort bus.

d. Combustion Chamber Pressure Switches

Two pressure switches were mounted on the engine to sense chamber pressure. With a rise in chamber pressure, the switches actuated, locking in relays K19 and K20, and placed the chamber pressure switches in the abort circuit. This lock-in feature prevented aborts due to nonactuation (failure) of the switches during thrust buildup. The two switches were in parallel circuits to eliminate the possibility of an abort signal not being given due to a failure of one of the switches after liftoff. At approximately "calculated cutoff minus eight seconds," K6 actuated, switching the pressure switches from the abort to the normal cutoff circuit. This was necessary to prevent an abort during normal shutdown.

e. Emergency Cutoff by Range Safety Officer

Engine cutoff by the Range Safety Officer was prohibited until 30 seconds after liftoff. At that time relays K5 and K16, not shown on the schematic, "dropped out" the engine main stage relay, thus permitting cutoff. These two relays were employed to provide redundant signal paths for cutoff.

abort. Relays K5 and K16, the two emergency cutoff relays, were operated by command receiver No. 1 and command receiver No. 2, respectively, and like the command receivers, were powered from independent 28-volt supplies. These relays triggered the abort bus and started two timers which blocked the fuel dispersion (destruct) system for three seconds after receipt of an emergency cutoff command. This eliminated the possibility of fuel dispersion before an attempted abort.

f. Capsule Abort

If the astronaut initated an abort, the signal opened contacts K17-1 and K17-2, which initated abort and engine cutoff as stated above, cutoff was blocked until after liftoff.

All wires which supplied abort signals or power from the launch vehicle to the capsule were duplicated for redundancy.

- Abort Relay

The abort contacts K7-1, -2, -3, and -4, were tied directly to the abort bus. Contacts K7-1 and K7-3 provided the lock-in feature to the abort bus when liftoff relay, K3, was de-energized. Once the abort bus was energized from any of the abort sensors, the bus locked-in if the vehicle had moved 3/32 of an inch, an amount sufficient to de-energize the liftoff relay. Abort could also be initiated up to liftoff by command from the ground through a hardwire connection to the capsule. After liftoff, ground command of abort could only be given through the capsule command receivers. The abort relay gave an abort signal directly to the capsule and would initate engine cutoff 30 seconds after liftoff. As an additional safety feature the vehicle electrical system supplied the capsule a constant 28-volt signal through the series-normally-closed contacts of K7-1 and -2, K7-3 and -4. This inadvertant loss of electrical power to assured abort by removing power from the abort circuit to the capsule.

- Engine Cutoff

Engine cutoff could be initiated by six sources subsequent to liftoff plus thirty seconds:

a. Abort (by energizing the command receiver relays).
b. Integrator velocity cutoff.
c. Propellant depletion (by means of combustion chamber pressure switch within 8 seconds of calculated cutoff).

d. Abort from capsule

e. Cutoff command from Launch Director (until liftoff).

f. Emergency cutoff by Range Safety Officer.

5.2.7.2 Attitude Error Sensor

The function of the attitude error sensor was to actuate the abort bus if the vehicle deviated beyond prescribed limits in pitch, yaw, and roll attitudes prior to engine cut-off. Three bi-stable voltage sensing triggers, each with two independently adjustable OR-type inputs were used. The input signals were derived from the potentiometer pickoffs on the LEV-3 gyros, and the sensor output actuated the abort circuit.

- Design Requirements

  a. Supply voltage on 28 volts dc $\pm$ 10 percent.

  b. Reference voltage 50 to 60 volts dc.

  c. Temperature range $0^{o}C$ + $55^{o}$ C.

  d. Vibration (reference Paragraph 5.3.3).

  e. Input impedance 50 K ohms or greater shunted by no more than 0.005 microfarads of capacitance.

  f. Minimum response time of 10 milliseconds.

- Abort Limits and Tolerances

| | Abort Limit | Tolerance |
|---|---|---|
| Pitch | 5 degrees | Plus 1.0 degree, minus 0 degree |
| Yaw | 5 degrees | Plus 1.0 degree, minus 0 degree |
| Roll | 10 degrees | Plus 2.0 degree, minus 0 degree |

- Circuit Description

  The basic curcuit is shown in the block diagram, Figure 5-9. Each gyro had two potentiometers mechanically connected to rotated in opposite directions. The difference in potential between the sliders furnished a signal corresponding both in magnitude and polarity to gyro rotation. Identical polarity triggering curcuits compared the signal from each slider with respect to ground, and determined when the limits of rotation in each direction were reached.

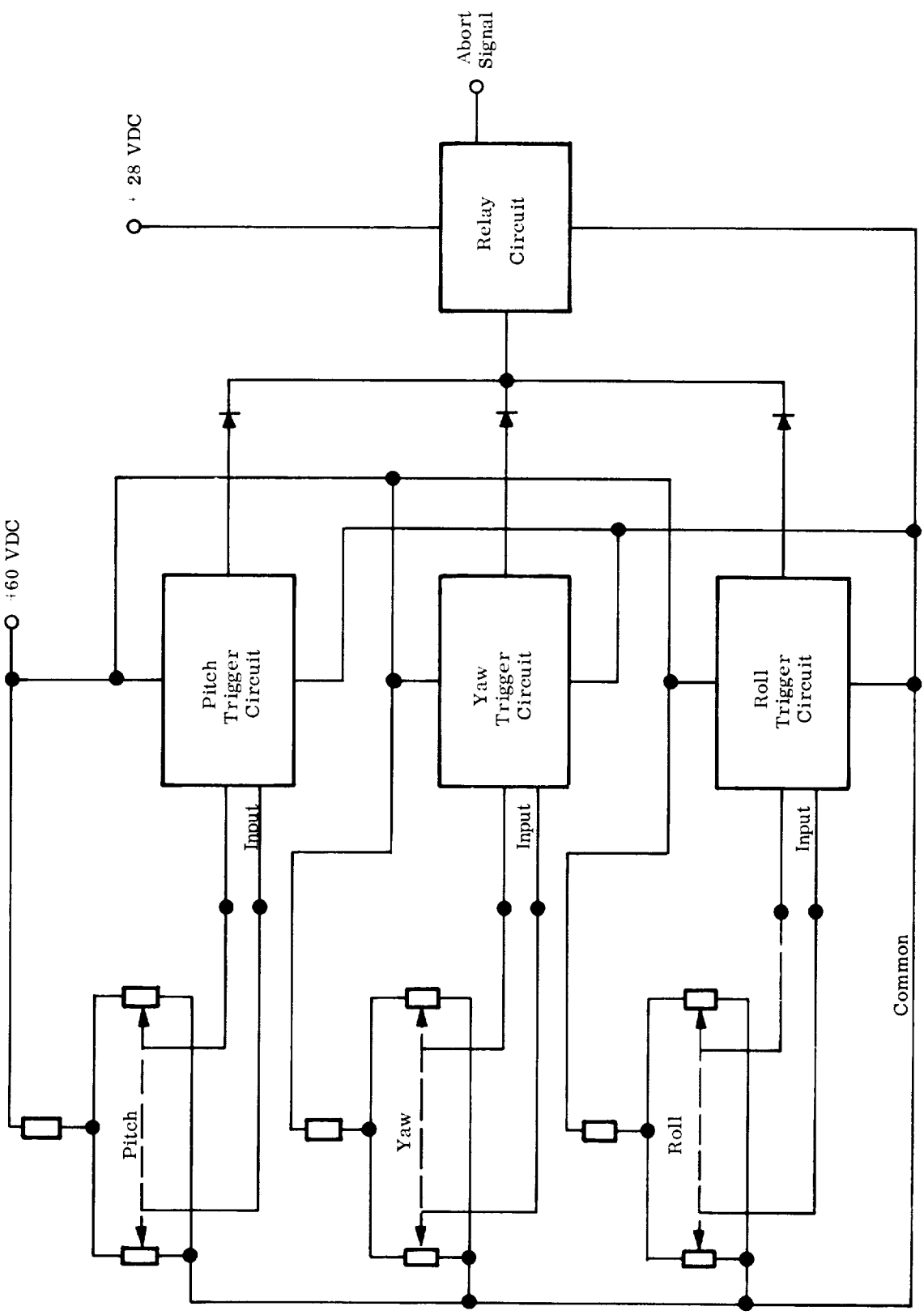



Figure 5-9. Attitude Error Sensor Block Diagram

The trigger input circuit consisted of a PNPN gated-diode used as a voltage sensing element which was turned on or off by varing the base (gate) voltage. The trigger voltage point (abort limit) was set by varying the emitter bias. The trigger input was part of a unijunction transistor oscillator circuit. Output from the oscillator was rectified and amplified to operated a relay with contacts in the abort circuit.

Circuit details may be seen on the schematic diagram (Figure 5-10). The cathode of the PNPN diode was biased such that when the desired input voltage was reached the PNPN diode conducted in the forward direction causing the unijunction oscillator to operate. Oscillation was sustained until the input voltage was reduced below the PNPN diode turn-on value. The diode in the emitter circuit provided reverse voltage protection for the PNPN diode. The potentiometer in the emitter circuit was used to adjust the operating point to the desired (abort) level. Complete voltage compensation for varying supply voltages was achieved by use of a zener diode and potentiometer in the reference circuit. The zener diode acted as the constant voltage source, and potentiometer adjustment provided compensation for large variations in supply voltages. A thermistor and resistor combination in the reference voltage network provided temperature compensation.

Oscillator output was capacitor-coupled to a rectifier circuit. The coupling diodes in the rectifier circuit prevented changes in trigger level or oscillator operation due to voltage variations and dc level changes in the relay circuit. The rectified output was fed to a dc amplifier stage that powered the relay which energized the abort circuit. The capacitor in the base circuit of the amplifier provided a time delay. This precluded an abort signal arising from transients above the sensor limits by requiring the oscillator to sustain operation for a sufficient time to charge the capacitor. The resistor and diodes provided bias and temperature compensation. The relay in the collector circuit was shunted by a capacitor and diode to remove transient voltage spikes that occurred when the circuit was de-energized.

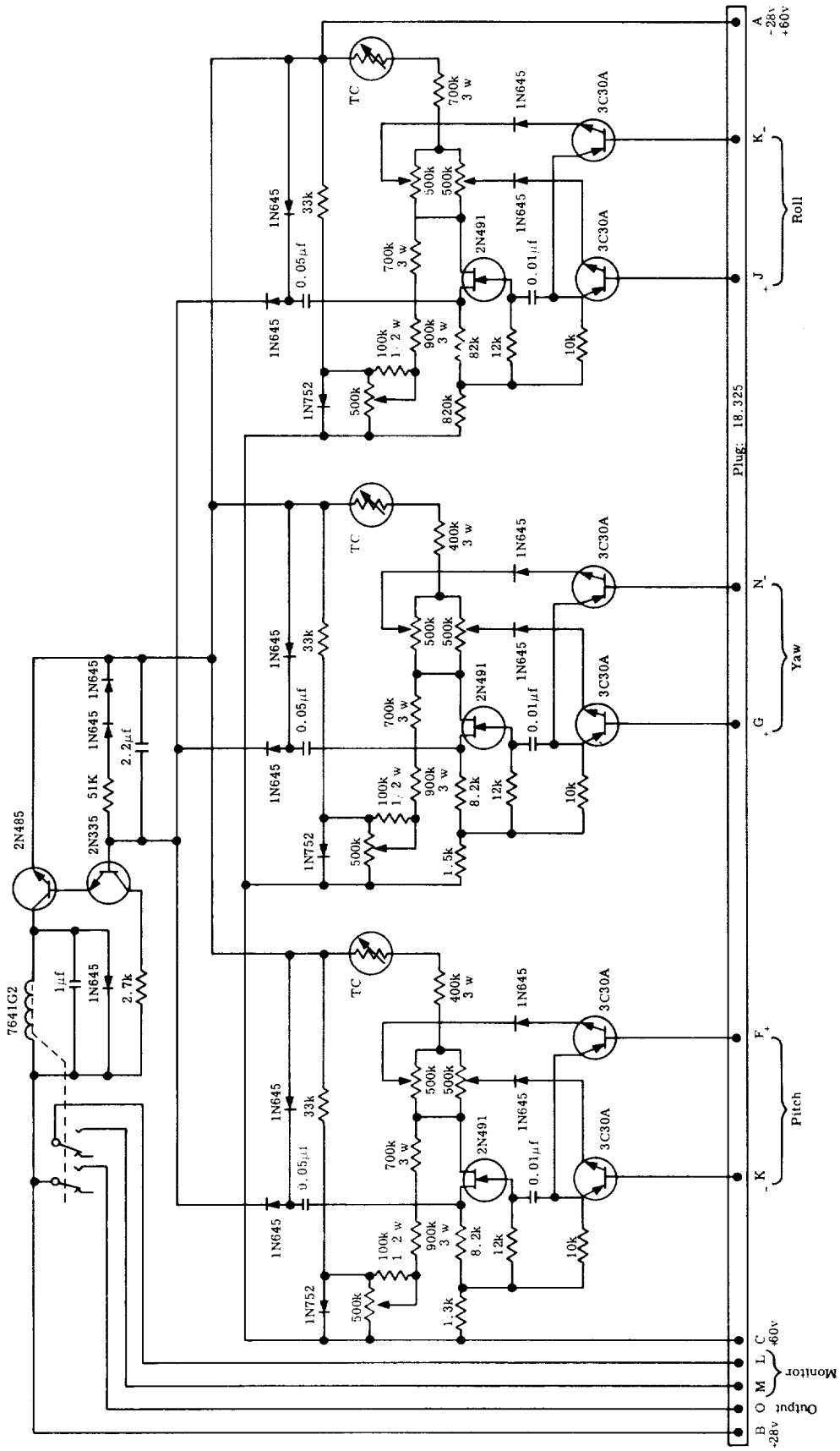



Figure 5-10. Attitude Error Sensor Circuit

- Failure Consequences

  Failure of the following attitude sensing components could have caused an abort:

  a. Open circuit input.
  b. Short circuit of the PNPN diode.
  c. Short circuit of the coupling capacitor between oscillator and dc amplifiers.
  d. Short circuit of either transistor in the output.
  e. Open or short circuit of the resistors or diodes in the reference network.

Loss of either 28 or 30 volts power within the sensor circuit would not have caused an abort, nor would failure of any component not mentioned above.

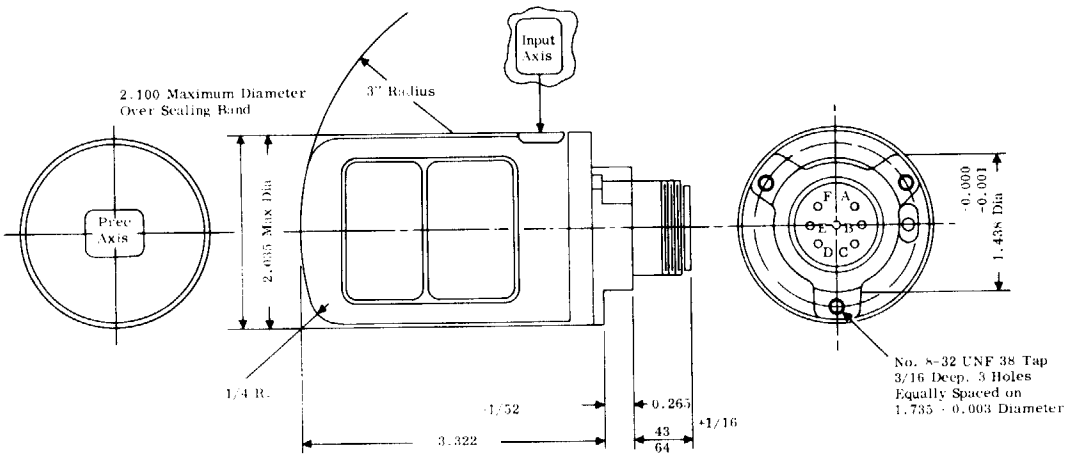
5.2.7.3 Attitude Rate Switches

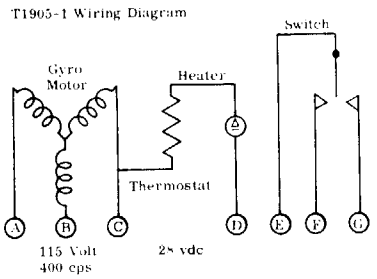
The rate switch (figure 5-11) was a spring-restrained, miniature gyroscopic device operating to close a set of contacts at a predetermined angular rate of turn. It was capable of sensing angular rates CW or CCW about its input axis. Units were mounted to indicate changes in pitch, yaw, and roll attitude. Yaw and pitch rate switches built for MERCURY-REDSTONE were designed to close at attitude rates of 5 degrees per second; the roll switch closed at a roll rate of 12 degrees per second. Tolerances on the pitch and yaw rates were plus 0.3 degree per second, minus 0 degree per second and on the roll rate were 0.6 degree per second, minus 0 degree per second.

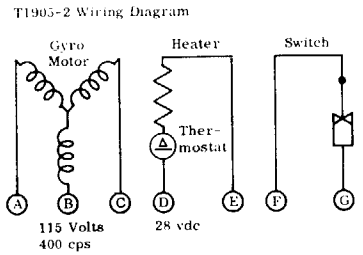
Three separate switches were used to sense motions of the vehicle in the pitch, yaw, and roll axes. Only the pitch and yaw rate switches were used to signal abort. The roll rate switch output was used only for monitoring that performance parameter.

The rate switches consisted of a gyro supported on bearings, a viscous damping device, and switch contacts. The gyro's gimbal displacement was proportional to angular velocity (or rate) about its sensitive axis. In the absence of an angular velocity about the input axis, the gimbal displacement was zero. The gyro used a single pole, double-throw switch which closed at the abort limits.

Motor power was 115 volts 400 cps. In the event of power failure, the angular momentum of the gyro was sufficient to insure operation for several minutes; however;




Mechanical Data

| | | |
|---|---|---|
| Unit No. | T1905-1A-15 and T1905-2A-15 | T1905-1B-15 |
| Closing Rate | 12°/Min. to 17°/Min. | 12°/Min. to 18°/Min. |
| Temperature Range | -54°C to +71°C | |
| Weight | 1.5 Pounds Max. | |

Electrical Data

| | |
|---|---|
| Power Requirements | Motor: 115 v. 400 cps. 3 Phase<br>Heater: 28 v. Direct Current |
| Power Consumption | Motor Starting Power 110 watts (max.)<br>Volt Amps - 19.0 v.a. (max.)<br>Motor Running Power - 5.5 watts (max.)<br>Volt Amps - 14.0 v.a. (max.)<br>Heater: 30 watts (intermittent) |
| Warm Up Time | 4 minutes below 25°C<br>1.5 minutes above 25°C |

Specifications

| Type | T1905-1A-15 | | T1905-1B-15 | | T1905-2A-15 | |
|---|---|---|---|---|---|---|
| Rate of Turn | 45°/Min. | 90°/Min. | 45°/Min. | 90°/Min. | 45°/Min. | 90°/Min. |
| Contacts Reopen Within | 5 Sec. | 6 Sec. | 3 Sec. | 4 Sec. | 5 Sec. | 6 Sec. |

Motor: Angular momentum 5x10 gm-cm²/sec.
Speed 24,000 rpm
Time to reach synchronous speed - 30 seconds

Operating Life: 1000 hours

Shelf Life: 5 years

**Figure 5-11. Attitude Rate Switch**

there would have been a slight increase in the angular velocity required to give the abort signal. Also, if the gyro failed, the switch contacts would have remained in the open position and would not have caused abort.

All electrical connections were brought out through a hermetically sealed connector located on the end of the housing.

The rate switches were hermetically sealed in an environment consisting of a dry inert gas which prevented corrosion. The switches had a minimum operating life of 1000 hours. The switch springs were of low hysteresis material, and the bearings were selected for their ability to retain low friction characteristics, thus assuring a high degree of accuracy and resolution throughout their operating life. The switches were built to withstand vibrations between 20 and 2000 cps.

A rate switch monitor was in series with the output of the rate switches and was used to give an indication to telemetry when an abort, caused by the switches, had occurred. It had no function in the abort sensing system except as a telemetry transducer.

The rate switch was connected as shown in Figure 5-12. The switch contact, when closed by excessive angular rates applied 28 vdc to the abort bus through a diode, and to telemetry through the second diode and a voltage divider in the measuring distributer. If the abort bus was energized by any of the other sensors connected to it, the diodes blocked this signal from the rate switch telemetry readout. The rate switch monitor circuit diagram is shown in Figure 5-13.

5.2.7.4 Control Voltage Detector

The attitude error signals from the potentiometer pickoffs of the LEV-3 gyros depended upon the 60 volt dc control voltage. Loss of this voltage would have resulted in loss of control of the vehicle and loss of the abort sensing system's attitude error sensor. For the MERCURY-REDSTONE abort sensing system, it was decided to monitor this supply voltage to assure that the absence of an abort signal from the attitude error sensor did not cause a serious decrease in or loss of control voltage potential.

Although at the initiation of the MERCURY-REDSTONE Program, the exact circuitry anticipated for the control voltage detector had not been used, very similar circuits had been employed for delay timer applications in other systems. The timers had

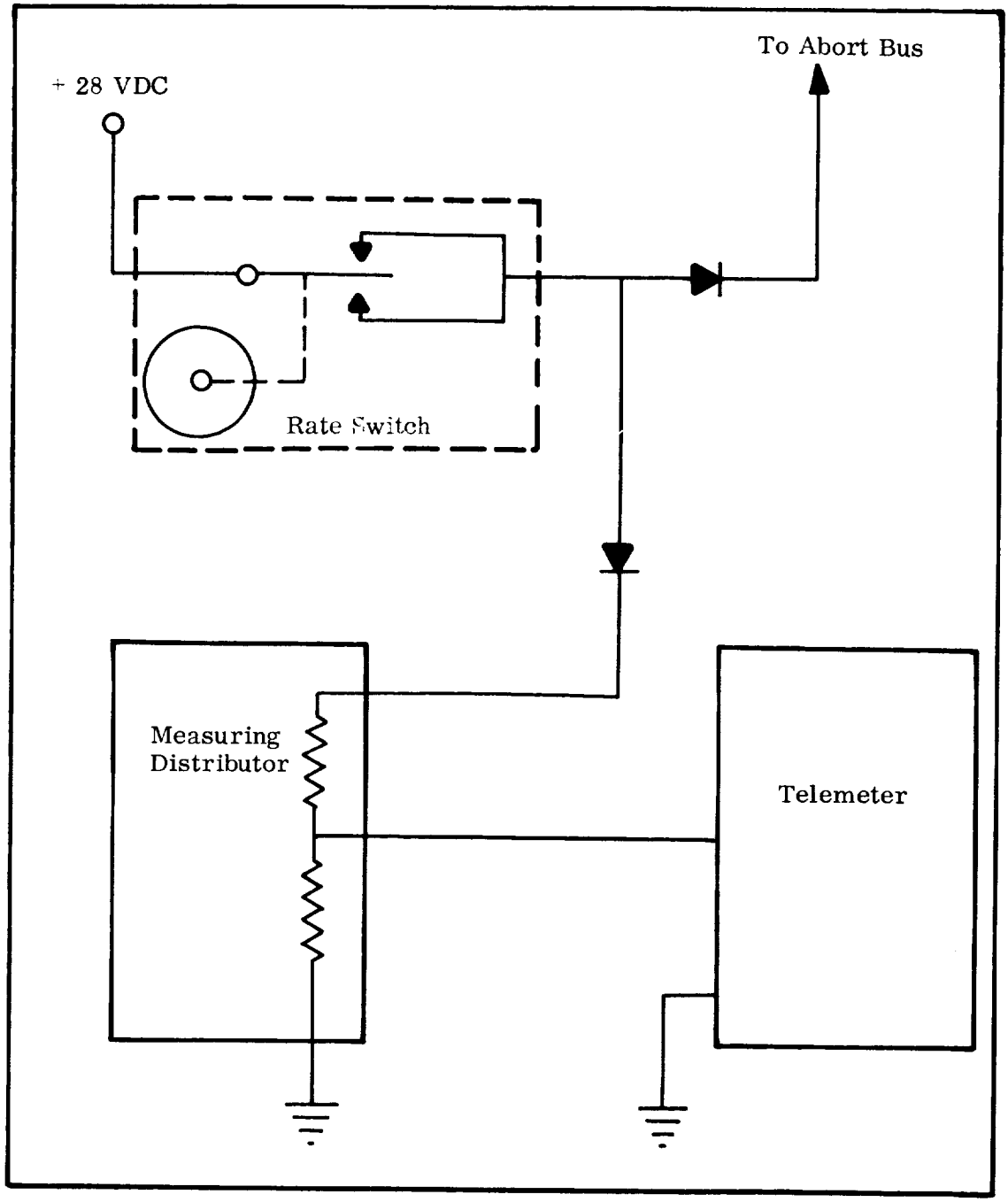



Figure 5-12. Attitude Rate Switch Block Diagram

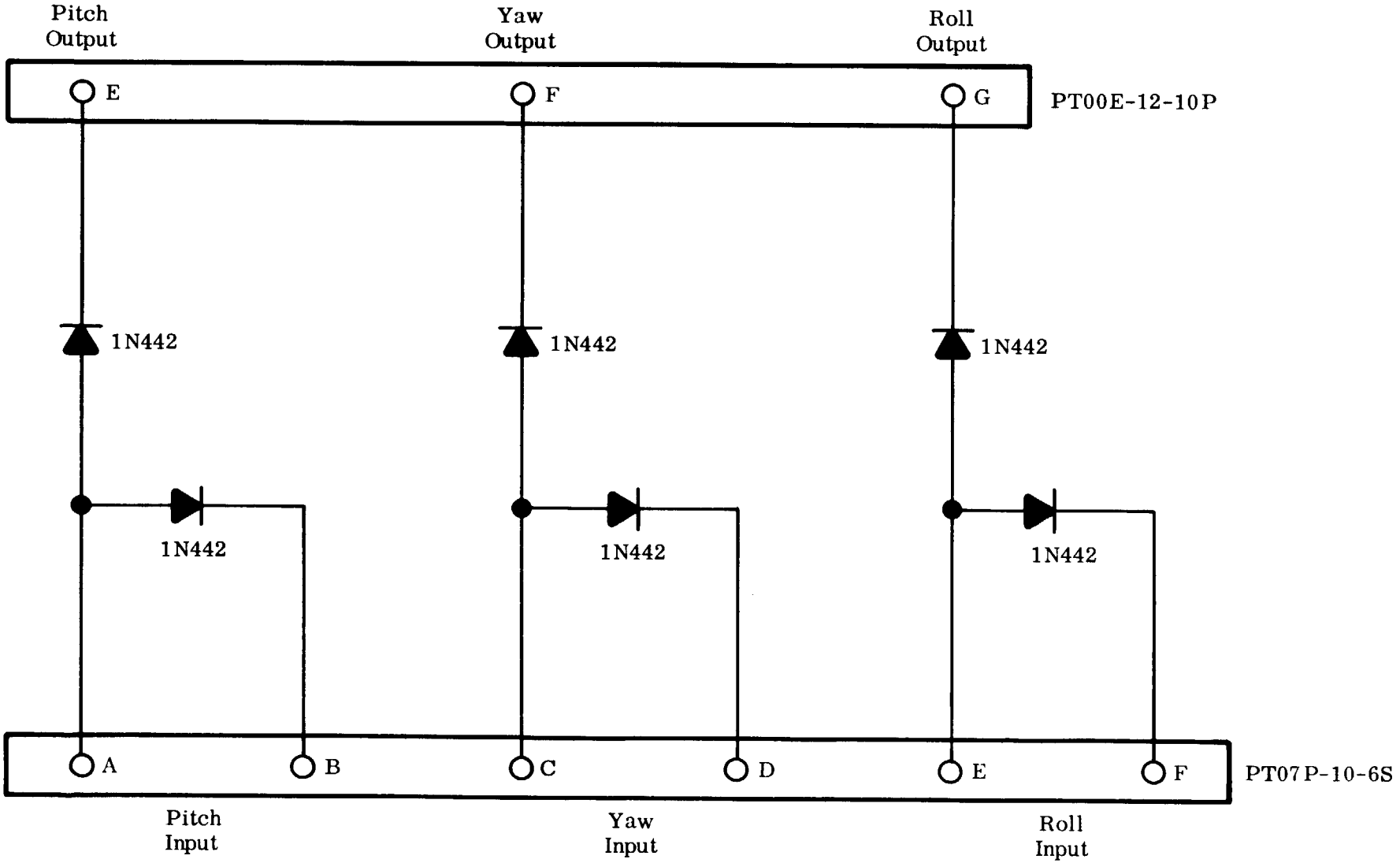



Figure 5-13. Attitude Rate Switch Circuit

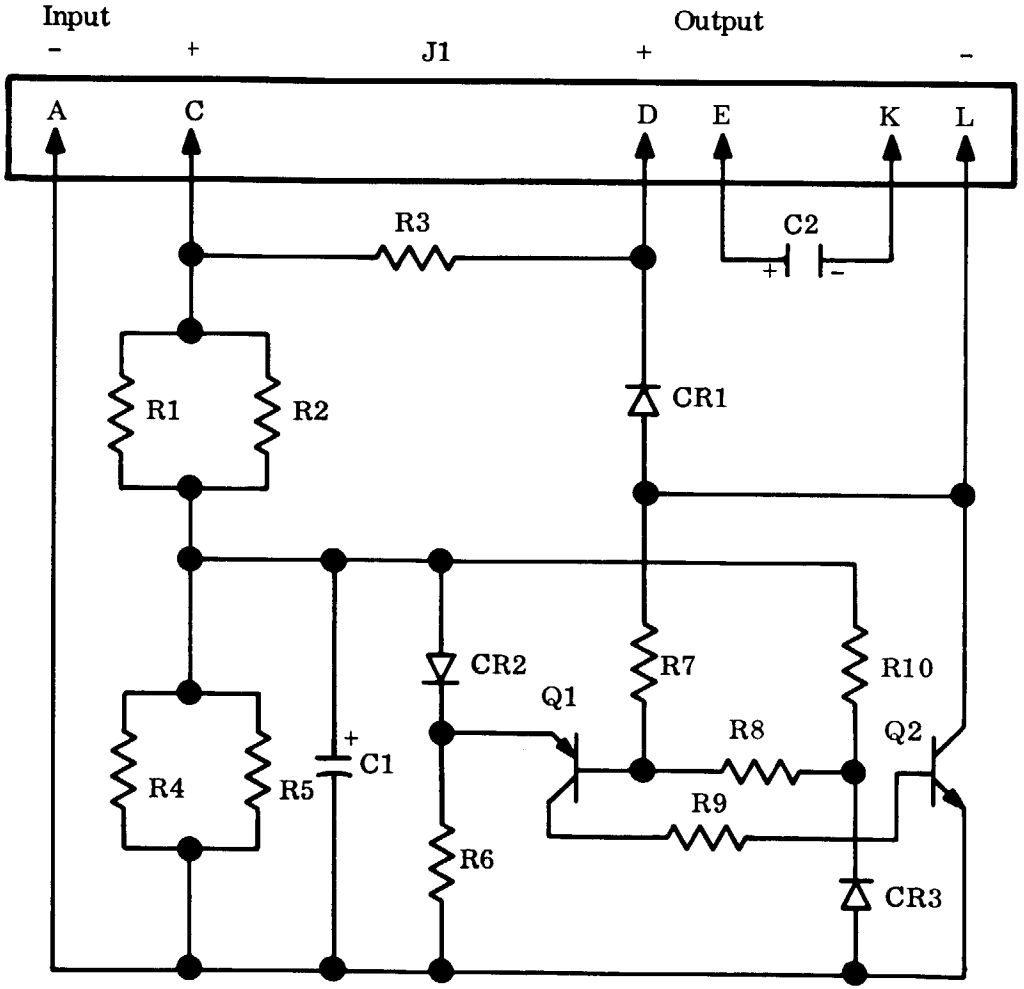
been extensively tested to JUPITER environmental requirements. Three such timer units per missile (separation timers and reverse thrust timer) had been employed with excellent success in every JUPITER missile since AM-9. In addition, similar circuitry had been used successfully as shroud timers in the JUNO II program, as pod timers in the HARDTACK program, and as ground voltage sensors in the JUPITER system.

Detailed performance tests were conducted by Quality Division prior to use of the control voltage detector in the MERCURY-REDSTONE system. Six of the Units were environmentally tested and all six units performed satisfactorily within launch vehicle specifications. The deviation from design specifications was at low temperature ($0^{o}$F). The differential voltage between pickup and dropout fell below one volt on three of the test units. The temperature extreme was far below launch site temperatures, and the deviation was not considered relevant to the vehicle mission (reference paragraph 5.3.3).

The control voltage (60 volt dc nominal) was monitored by a voltage divider network which drove a bridge circuit formed by CR2, R6, CR3, and R10 (Figure 5-14). This bridge circuit, dependent upon the sensed voltage, was balanced or unbalanced. If the sensed voltage remained within its specified 60-volt range, the bridge circuit was unbalanced and transistor Q1 conducted driving transistor Q2. Conduction by the transistors maintained the output relay in the energized position. A drop of the sensed voltage to 50 volts drove the bridge into a balanced stage causing Q1 to be cut off. Positive feedback action of resistor R-7 accentuated the cutoff action and maintained the transistor circuitry in cutoff condition. With Q1 and subsequently Q2 cutoff, the output relay was immediately de-energized actuating abort circuitry. For voltages below 50 volts the bridge circuitry became unbalanced in such manner as to cause the transistors to be biased to cutoff.

The control amplifier was a medium power, silicon transistor stage which functioned as an on-off switch for the output relay. Sharp triggering of this stage provided snap-off operation of the output relay at the critical input level.

Capacitors, C-1 and C-2, assured that circuit operation would not be adversely affected by voltage transients. Design criteria required a delayed action of approximately 100 milliseconds in order to compensate for negative voltage transients. Unless this dealy was included, the control voltage detector would detect and initiate an abort signal as a result of a negative transient.




Electrical Components List

| Find No. | Description |
|---|---|
| C1 | Capacitor, Solid Tantalum, 55 MFD 25 vdc, 4T304 |
| CR1 | Diode, Submin Silicon |
| CR2 | 1N457, 60 Volts PIV |
| J1 | Connector, 10 Pin Male, Printed Circuit, No. 4202 |
| R1 | Resistor, 2K, 3 Watt, 10 Percent |
| R2 | Resistor, 2K, 3 Watt, 10 Percent |
| R3 | Resistor, 700 Ohm, 3 Watt, 10 Percent |
| R4 | Resistor, Test Select, 1 Watt |
| R5 | Resistor, Test Select, 1/2 Watt |
| R6 | Resistor, 1.2K, 1/2 Watt, 5 Percent |
| R7 | Resistor, Test Select, 1/2 Watt |
| R8 | Resistor, 4.7K, 1/3 Watt, 5 Percent |
| R9 | Resistor, 1.9K, 1/3 Watt, 5 Percent |
| R10 | Resistor, 1K, 1/3 Watt, 5 Percent |
| Q1 | Transistor, Silicon Junction 2N1026 |
| Q2 | Transistor, Silicon Junction 2N498 |
| CR3 | Diode, Zener Regulator SV132 |
| C2 | Capacitor, Tantalytic, 60 MFD 50 vdc, VP60840A1 |

Figure 5-14. Control Voltage Detector Electrical Schematic

Capacitor, C-1, provided a time delay of 50 milliseconds for a negative voltage transient of 20 volts. Capacitor, C-2, across the relay coil increased the time delay to the required 100 milliseconds.

When the control voltage was in the safe range, the output relay was energized and the output contact was open.

However, when the control voltage dropped below the critical 50 volt level, the control amplifier de-energized the relay causing 28 volts dc to appear at the output through a set of normally closed contacts. This mode of operation required both safe input voltage and proper circuit operation for no output signal.

To assure maximum safety and reliability, the circuitry of the control voltage detector was designed so that all components were used at power levels well below their rating. To prevent a false abort, two detector circuits were used in series thus allowing one to block the abort signal if the other detector should fail.

5.2.7.5 Chamber Pressure Sensor

The combustion chamber pressure was monitored with two redundant pressure switches. These switches were mounted on the thrust frame with chamber pressure supplied to them by independent pressure tubes.

When pressure was applied to the switch, Figure 5-15, the force developed on the diaphragm was transmitted through a preloaded spring to a microswitch. Increasing pressure actuated the microswitch and armed the pressure switch. Subsequent decreasing pressure would deactivate the microswitch and cause an abort signal. The preloaded spring controlled the arm and abort actuation points and was adjusted as shown in Figure 5-2.

The method of sequencing assured proper engine operation prior to arming the switch and prevented false abort in the event of pressure fluctuations during thrust buildup. Since any loss of pressure would signal an abort, the pressure switches were switched out of the abort circuit prior to a normal engine cutoff.

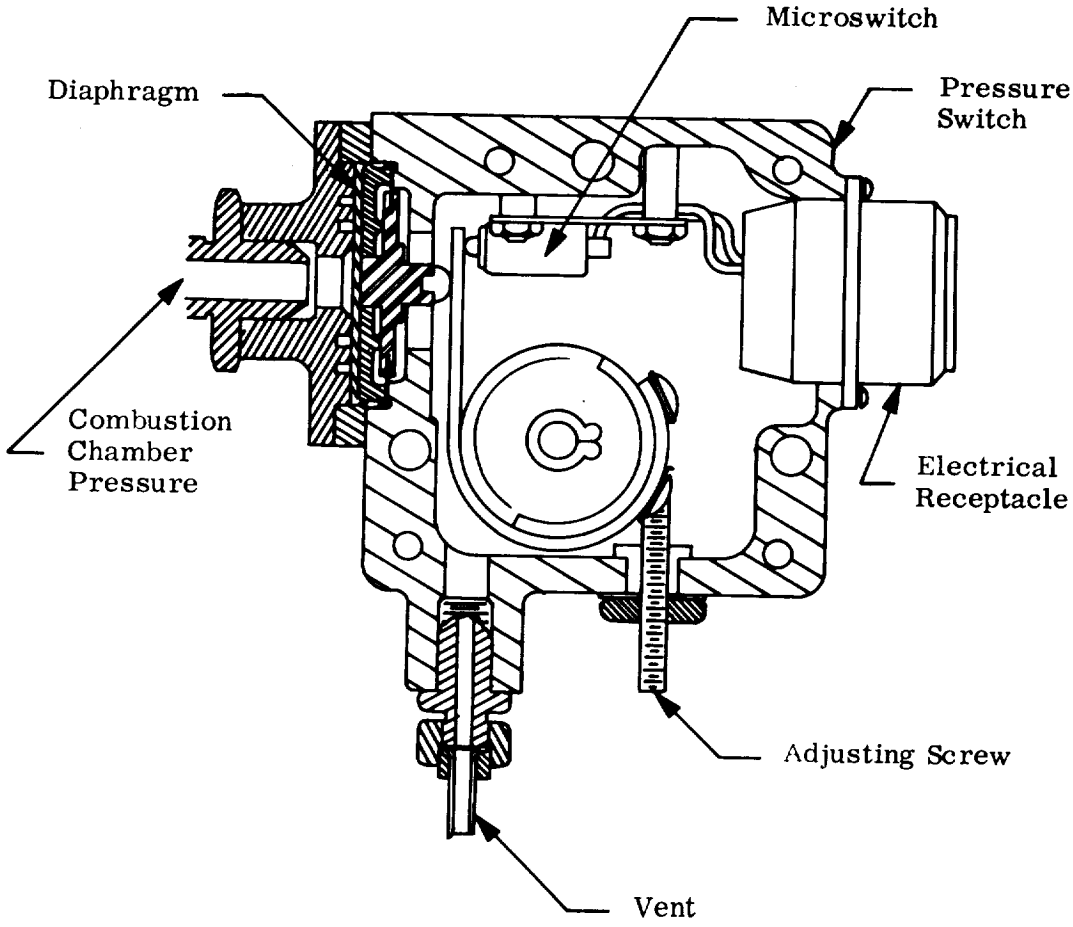



Figure 5-15. Chamber Pressure Sensor

## 5.3 RELIABILITY PROGRAM

### 5.3.1 INTRODUCTION

It was evident at the beginning of the program that mission reliability had to be increased above that indicated by the tactical missiles. Since the REDSTONE had an extensive flight history, many of the weak areas of its design and performance had been identified and improved. In contrast, the abort system and capsule interface were new. A reliability program was thus established to upgrade the booster and assure the proper operation of the new components.

### 5.3.2 RELIABILITY TESTING

A developmental test program was conducted to prove the REDSTONE's adaptation to the MERCURY Program. A major protion of this test program was called the MERCURY-REDSTONE Reliability Program. The successful program found potential

problem areas, developed satisfactory solutions, and established procedural and quality standards. Tests in the total program included the following:

- Factory Testing
  a. Aft section tests including abort system.
  b. Tail section tests.
  c. Propulsion subsystem tests.
- Structural Load Simulation
  a. Thrust unit flight simulation.
  b. Transportation load simulation.
- Static Firing - Noise and Vibration
- Capsule and Adapter
  a. Mating compatibility test.
  b. Flight adapter checkout.
  c. Separation ring test.
- Component Qualification and Development Tests.

The factory testing was a combined temperature-humidity-vibration test series conducted by Chrysler Corporation's Missile Division (CCMD). Also conducted by CCMD were the structural load simulation tests on the thrust unit. This test included application of bending, shear, and longitudinal loads simulating flight and transportation loads.

A static firing test conducted by MSFC measured noise and vibration at several points on the missile, adapter, and capsule. Functional and mating compatibility tests were also made at MSFC with the capsules for MR-1 through MR-BD. A checkout was made on each flight adapter starting with the adapter for MR-3. In addition several component development and qualification tests were made to solve individual problem areas and prove flight readiness. The details of these tests and their results are described in Section 6.

Of special note was a total system-environment test of the Instrument Compartment containing the abort sensing system. The test was made on a specially designed "rock and roll" test fixture, formally named the Vertical Test Fixture (Figure 6.3). This was probably the biggest and most important ground test effort of the program. The abort

system was operated under actual angular rates and attitude changes, coupled with vibration, humidity and temperature environments. Additional details are given in Section 6.3.3.

### 5.3.3 ABORT SYSTEM RELIABILITY TEST PROGRAM

Of special interest was the program designed to assure a high abort system reliability. The plan for this program is presented here.

The plan called for testing of systems and subsystems. In addition to testing large groups of components simultaneously, this method had the advantage of testing the various components and their interaction. Such tests were conducted at the Chrysler plant. In addition, qualification tests were conducted for each component of the abort system at MSFC.

Using three or more units of each of the components composing the abort system, a modified test-to-failure program was to explore the modes of failure, environmental levels of failure, and critical operation and environmental conditions. The purpose of the tests was to isolate any mode of failure so that necessary corrective action could be taken. The tests were designated as follows:

- First Level

  Each component was tested under those environments expected prior to and during flight.

- Second Level

  Each component was stressed operationally and environmentally at the expected maximum capability of that particular component.

- Each component was stressed under a predetermined critical environment until failure occurred.

Actually two test plans were developed which differed only in the levels of temperature, vibration, shock, and acceleration. Plan A (Table 5-4) was designed for the rate switches, voltage detectors, and attitude error sensors. These were contained in the pressure and temperature controlled instrument compartment. Plan B (Table 5-5) was designed for the combustion chamber pressure sensors because of their location on the engine.

Table 5-4

Abort Sensing System Reliability Test Plan A for Attitude Rate Switches, Attitude Error Sensors, and Voltage Detectors*

| Environment | First Level | Second Level | Third Level |
|---|---|---|---|
| Low Temperature | + 50°F | 0°F | - 25°F and +77°F |
| High Temperature | +120°F | +145°F | +160°F and +77°F |
| Vibration | 20 to 50 cps at 0.03 inch double amplitude 50 to 2000 cps at 4 g. | 20 to 50 cps at 0.06 inch double amplitude 50 to 2000 cps at 8g. | 20 to 50 cps at 0.09 inch double amplitude 50 to 2000 cps at 12 g. Repeat with g increased by 4 g increments until failure. |
| Shock | 10 g | 20 g | 30 g |
| Acceleration | 10 g Longitudinal 5 g Lateral | 20 g Longitudinal 10 g Lateral | 30 g Longitudinal 15 g Lateral |

* The number of samples tested were 6, except, only 3 attitude error sensors were tested due to component availability.

Table 5-5

Abort Sensing System Reliability Test Plan B for Combustion Chamber Pressure Sensors (6 Samples)

| Environment | First Level | Second Level | Third Level |
|---|---|---|---|
| Low Temperature | ——— | Same as in Table 5-4 | ——— |
| High Temperature | ——— | Same as in Table 5-4 | ——— |
| Vibration | 20 to 100 cps at 0.04 inch double amplitude 100 to 2000 cps at 20 g. | 20 to 100 cps at 0.06 inch double amplitude 100 to 2000 cps at 30 g. | 20 to 100 cps at 0.08 inch double amplitude 100 to 2000 cps at 40 g. |
| Shock | 25 g | 30 g | 40 g |
| Acceleration | ——— | NONE | ——— |

As shown in the tables, both plans call for temperature excursions. For these tests the equipments were to be stabilized at the indicated temperature, then soaked at this temperature for 2 hours prior to running functional tests. The third level test was really two tests; one at the extreme temperature and, after the soak cycle, one at room temperature.

Each component was first low temperature cycled at all three levels, high temperature cycled at all three levels, vibrated, shocked, and accelerated, in that order, at the three consecutive levels. The final test was a test-to-failure vibration. This last test was omitted for Test Plan B as well as acceleration testing.

The vibration test consisted of a 6-minute vibrational sweep from 20 to 2000 to 20 cps, except as g limited. The sweep was to locate resonances in all three major planes. The sensors were to be operating during the vibration and tested afterward to locate any vibrational damages. After the initial third level test, the g level was increased in 4 g increments and the frequency cycled until component failure.

The shock test was to be applied in both directions of all three axes for 12 milliseconds if triangular waveform was used, for 10 milliseconds if sinusoidal waveform was used, and 8 milliseconds if square waveform was used. The acceleration test consisted of a 5-minute acceleration in both directions of all three axes with simultaneous longitudinal and lateral acceleration along, and perpendicular to, the direction of test. After the shock and acceleration tests, functional checkouts were scheduled. No shock or acceleration test-to-failure tests were planned.

### 5.3.4 RELIABILITY STUDIES

After flight MR-2 the reliability of the MERCURY-REDSTONE was re-examined in regard to its suitability for manned flight (reference paragraph 8.3). Three separate studies were made. The first was based on the running average of flight success probabilities which would place the payload at the proper injection point. The second study was based on an artifical configuration using the flight record of all components, weighting their failures according to the number of flights made by each component. The third study will be defined later. The results of the running average investigation were as shown in Table 5-6. The results of the component evaluation were as shown in Table 5-7. The probability of booster success thus was estimated, as shown in the tables, to be between 78 percent and 84 percent at a 75 percent confidence level.

Table 5-6

MERCURY-REDSTONE Reliability Prediction (10 February 1961)* -A

| Probability Of | Straight Average | Running Average | |
|---|---|---|---|
| | | 50 Percent Confidence | 95 Percent Confidence |
| Booster Success | 81.2 | 80.3 | 77.4 |
| Crew Escape | 98.6 | 97.6 | 94.3 |

* Basis: All REDSTONE, JUPITER-C, and MERCURY-REDSTONE Booster Flights (69 Flights).

Table 5-7

MERCURY-REDSTONE Reliability Prediction (10 February 1961)* -B

| Subsystem | Number of F rings of Components Composing MR Subsystem | Probability of Booster Success 75 Percent Confidence as Based on | |
|---|---|---|---|
| | | Past Firings | Engineering Estimates ** |
| Propulsion | 10 to 67 | 90 Percent | 94 Percent |
| Structure | 10 | 96 Percent | 96 Percent |
| Control | 27 to 67 | 94 Percent | 96 Percent |
| Pressurization | 67 | 96 Percent | 99 Percent |
| Human Error | 67 | 96 Percent | 98 Percent |
| Total | 10 to 67 | 78 Percent | 84 Percent |

* Basis: MERCURY-REDSTONE Configuration as Composed of Subsystem Components

** Based on Component Improvements Achieved with Corrective Action.

Many components were originally designed to mission parameters exceeding those required for the MERCURY-REDSTONE mission. In addition, the launch operations personnel had developed techniques more conducive to satisfactory flight. These facts, coupled with the improvements incorporated on the vehicle with the low probability of inadvertent abort, led MSFC to the opinion that the MERCURY-REDSTONE launch vehi-

cle reliability was in the range of 88 percent to 98 percent probability for launch success and crew survival, respectively. The successful MR-BD flight gave the assurance that the MERCURY-REDSTONE was ready for manned flights.

As stated previously, a portion of these studies was an evaluation of all components comprising the launch vehicle. Most of these components or their prototypes had flow in earlier REDSTONE and JUPITER-C vehicles. The rating of the components and their allied systems necessarily considered not only the number of times flown but also any malfunctions which were known to have occurred and whether this type of malfunction had been completed eliminated for future flights. Thus, a third and more refined reliability study was made.

For the third calculation, the effect of each malfunction was carefull adjusted in value based on its possible contribution to a vehicle failure that could occur and adversely affect a MERCURY-REDSTONE mission. Particularly sensitive to such judgment was the impact of human errors. Both human errors and component malfunctions which had occurred during a recent firing were given more weight than the earlier occurrences. Consideration was also given to system design improvements, incorporated during the period of system use, and repetitive performance improvement or learning curve in both personnel performance and improved operational techniques. The malfunction and failure data thus derived was then examined for the possibility of occurrence in the MERCURY-REDSTONE vehicle, as fabricated and checked out under its more stringent standards of construction and quality assurance.

This component and system evaluation resulted in synthetic data which were deemed as representing reasonable expected failure or malfunction rates in the MERCURY-REDSTONE launch vehicle. Reduction of these data to a common confidence level was based on the assumption that the calculated reliability was the mean of all reliabilities represented by a series of samples of like size. A further interpretation of this implies that the calculated reliability represented the mean of the actual reliabilities of the individual flights. In addition, it was assumed that this hypothetical series of reliabilities followed a Gaussian or normal distribution. This derivation of an estimated standard deviation then permitted the determination of system reliability for various confidence factors.

The reliability estimates thus derived were presented in terms of confidence factors in which the level of confidence was interpreted to mean that the reliability estimated would be as stated or higher in the percentage of cases represented by the confidence level. Typical of such data derived at this point in the program was:

| Vehicle Reliability (Successful powered flight without abort) | Confidence Level |
|---|---|
| 84 Percent | 50 Percent |
| 75 Percent | 75 Percent |

An alternate method of data presentation to more readily permit a judgment of the spread in data is shown below. Here, the confidence interval expresses the percentage of cases which will lie within the expected or calculated reliability range.

| Confidence Interval | Reliability Range |
|---|---|
| 50 Percent | 75 to 94 Percent |
| 75 Percent | 69 to 98 Percent |

This portion of the study thus attempted to derive a reliability and confidence factor by comparing the MERCURY-REDSTONE vehicle components to previous flight history, allowing for differing systems operation, design modifications and improvements, changing procedures, and different missions. The data on which the above values are based are given in Table 5-8.

Table 5-8

Evaluation of Flight Data on MERCURY-REDSTONE Components

| | No. Flights | Observed Malfunctions | Weighted Failures* | Anticipated Failures** |
|---|---|---|---|---|
| Flight Control | | | | |
| LEV-3 | 27 | 4 | 1 | 0.75 |
| Network and Actuators | 67 | 6 | 2 | 1 |
| Structure | | | | |
| LOX manhole cover | 10 | 10 | 0.25 | 0.25 |
| Elongated tanks | 10 | 0 | 0 | 0 |
| Propulsion | | | | |
| $H_2 0_2$ regulators | 67 | 3 | 2 | 1.5 |
| A-7 engine | 10 | 4 | 0 | 0 |
| Thrust controller | 42 | 5 | 5 | 0.4 |
| $H_2 0_2$ lead start | 45 | 0 | 0 | 0 |

Table 5-8

Evaluation of Flight Data on MERCURY-REDSTONE Components (Cont.)

| | No. Flights | Observed Malfunctions | Weighted Failures* | Anticipated Failures** |
|---|---|---|---|---|
| Pressurization | | | | |
| Propellant and Turbine | 67 | 4 | 0.25 | 0.20 |
| Instrument Compartment | 67 | 1 | 0 | 0 |
| Human Errors | | | | |
| Personal | 67 | 5 | 2 | 1 |

* Weighted failures are those observed malfunctions which would cause (by engineering judgment) an unacceptable M-R booster flight.

** Anticipated failures are weighted failures that might not be eliminated on M-R boosters in spite of present corrective action.

## 5.4 QUALITY ASSURANCE AND MERCURY AWARENESS PROGRAM

### 5.4.1 GENERAL

The MERCURY-REDSTONE quality assurance program placed primary emphasis on eliminating the human errors in fabrication, assembly, inspection, and test. This was accomplished in a threefold effort that effectively used careful documentation, hardware, checkout, and personnel motivation.

### 5.4.2 MERCURY AWARENESS PROGRAM

The Mercury Awareness Program, dealt with the personnel motivation or the human aspect of quality. It inspired all individuals to do their best. MERCURY stamps were issued to trained people to use with discretion on approved documentation and hardware (Figure 5-16). Publicity and awards focused attention on the good work of conscientious people. This program was a keystone of quality and has since been repeated in every manned space program.

The importance of the MERCURY stamps should be noted. Since the REDSTONE was built as a military weapon system the MERCURY stamps identified the hardware which would carry a man into space. In addition to identification of MERCURY flight components the stamps promoted a psychological awareness of the ultimate use within each handler of the part. By 7 October 1959, use of these stamps established that only MERCURY-identified documentation and hardware were utilized throughout the MERCURY program. The stamps further identified preliminary and final status by circular and square

enclosures, respectively. Use of any spare parts or documentation not identified by the square stamp was prohibited. This identification procedure further assured that the 100 percent inspection directive for Project MERCURY was carried out.

### 5.4.3 DOCUMENTATION

The quantity of development documentation was increased only slightly over that of the tactical REDSTONE. Emphasis was placed on complete and accurate records rather than on additional forms. Standard REDSTONE instructions and specifications were used except where specific MERCURY documentation was required. Test procedures were reviewed and new mechanical and electronic procedure specifications prepared. Running time reports were kept on all parts, and functional and inspection test reports were required to be complete in all details.

### 5.4.4 QUALITY ASSURANCE TESTING

The improved documentation and procedures, assured proper testing and correct selection of components. Since parts for the MERCURY-REDSTONE Progam were being fabricated and processed coincidently with those for the tactical REDSTONE missile, the components whose characteristics were closest to the nominal were selected for the MERCURY Program; all others were assigned to the tactical REDSTONE missile. Once selected for Project MERCURY, all parts were identified with a MERCURY stamp.

Receiving inspection included each component. During systems buildup, inprocess inspections monitored quality of the combined units. Tests included magnaflux and radiographic inspection of engine parts, inspection of electrical soldering and cable construction, and acceptance tests which simulated conditions of application.

After assembly a booster checkout was conducted. Since all components and subsystems had been inspected, functionally tested, and installed, the final checkout was used to determine that they would work as a single vehicle system. In this checkout, power was applied and each system checked out separately. Then compatibility tests were run to insure that no deteriorations had occurred as a result of the intercoupling.

The final factory test was the simulated flight test. The ground equipment system was connected using actual launch equipment where feasible and simulated where flight equipment could not be operated. The test began with a launch countdown and the

equipment was operated sequentially in the same order as it would on an actual flight. Telemetry recordings were made through an RF link. At the completion of the test, the records were examined for proper equipment operation. If the records were good, the vehicle was acceptable for launch use.

Special procedures were also established for the testing and selection of spare parts for each booster. All spare assemblies and subassemblies, assigned to a specific vehicle, were checked for compatibility at MSFC during checkout tests. These parts were then identified by missile number and, if not used at the launch site, were returned for checkout with a subsequent reassignment.




Figure 5-16. MERCURY-REDSTONE Manned Flight Awareness Stamp

# SECTION 6

# DEVELOPMENT TEST PROGRAM

## 6.1 INTRODUCTION

The MERCURY-REDSTONE development program included the normal ground test required in all launch vehicle programs plus those added due to the manned payload. Thus, in addition to a description of the mechanical and electrical checkout testing, this section includes details of special reliability and vibration dampening programs. The booster recovery program is also covered as it was the first such program to reach the test phase. The flight development tests are detailed in Section 8.

## 6.2 VEHICLE TEST PROGRAM

### 6.2.1 GENERAL

The MERCURY-REDSTONE test program retained the high quality test procedures used for component selection and booster assembly. Only after the vehicle neared full system status were special systems tests necessary. The final systems tests to which the launch vehicle was subjected were the following:

- Mechanical assembly analysis.
- Static firing.
- Alignment (mechanical).
- Pressure and mechanical function.
- Continuity (electrical).
- Network (includes over-all No. 1).
- Radio frequency systems.
- Guidance and control system.
- Over-all test No. 2.
- Instrument calibration.
- Over-all test No. 3.
- Simulated flight test (electrical).
- Final pressure and functional analysis.

The testing sequence was based on the pyramidal testing philosophy, whereby components, subsystems, and finally the entire vehicle was functionally checked. This type of testing, illustrated in Figure 6-1, verified proper operation of all hardware within the vehicle.

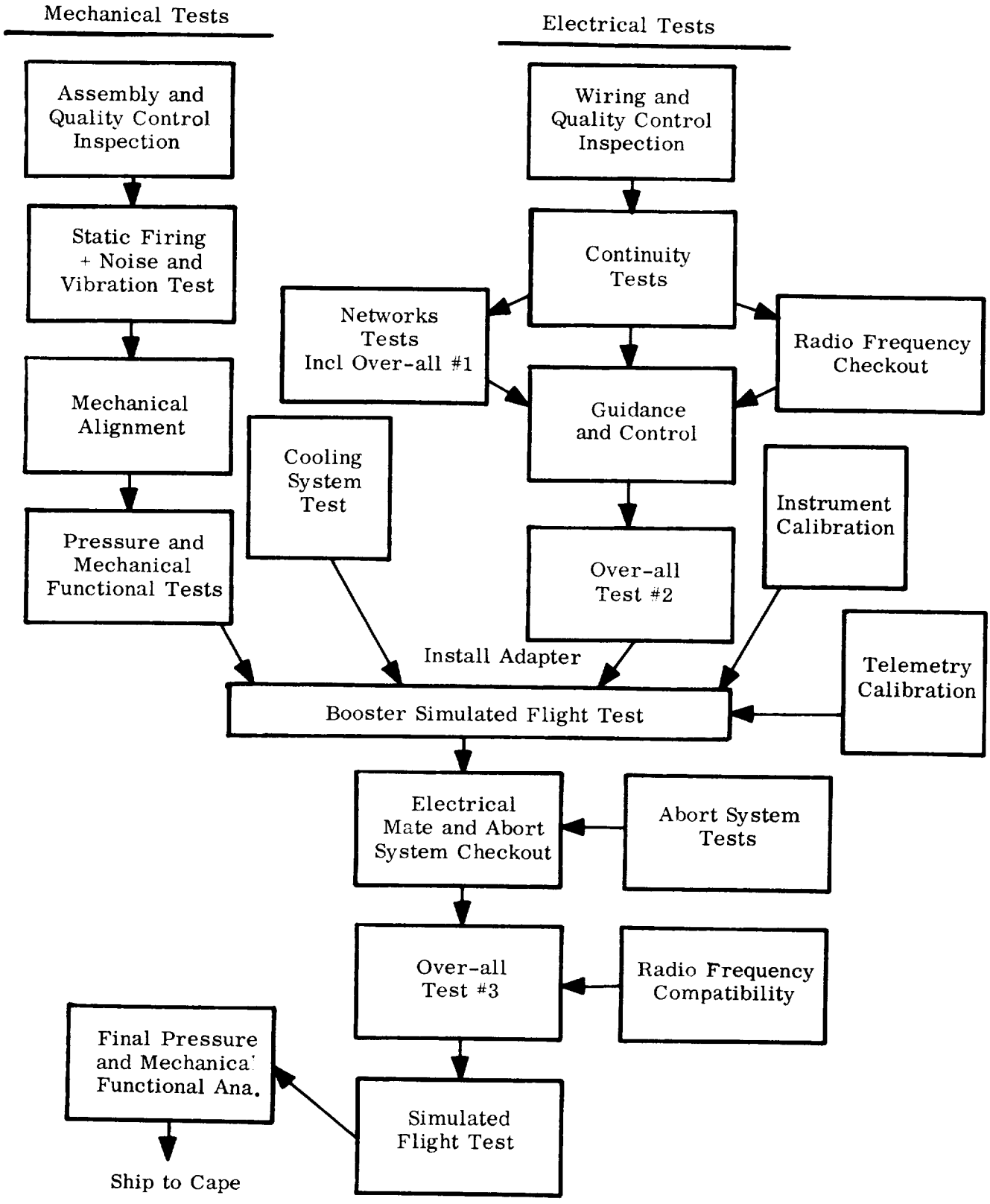



Figure 6-1. MERCURY-REDSTONE System Test Flow Diagram

Within this section, reference to boosters will be made based on their assembly number, not their ultimate flight number; e.g., booster MR-8, which served as the launch vehicle for Flight MR-4, shall be referred to as MR-8. This notation on the use of nomenclature is necessary due to the similarity of the numbering systems. A cross tabulation of booster and flight numbers is as follows:

| Booster No. | Flight No. |
|---|---|
| MR-1 | MR-1 |
| MR-2 | MR-2 ("Ham") |
| MR-3 | MR-1A |
| MR-5 | MR-BD |
| MR-7 | MR-3 (Shepard) |
| MR-8 | MR-4 (Grissom) |
| MR-4 | Not Launched |
| MR-6 | Not Launched |

### 6.2.2 MECHANICAL ASSEMBLY ANALYSIS

Although assembly analyses were performed throughout buildup, a final mechanical analysis was performed on each vehicle prior to assembly release. Difficulties encountered during the analysis resulted in either replacement of faulty components or rework. All deviations from specified documentation were documented by a Waiver Approval Request. A standard modification was made on Boosters MR-3, -5, -7, and -8. On these vehicles the LOX tank manhole cover, gasket, and LOX tank bulkhead flange were modified by increasing the bolt hole diameters to 0.390 ± 0.005 inch, replacing the 5/16 inch steel bolts with 3/8 aluminum bolts and torquing these bolts to 175 ± 5 inch-pound. In the event it was necessary to disassemble the manhole cover, replacement of the 3/8 inch aluminum bolts was required due to the high torque value used.

### 6.2.3 STATIC FIRING

#### 6.2.3.1 Introduction

As part of the prelaunch procedures and checkouts, each of the eight MERCURY-REDSTONE launch vehicles was scheduled for static firing tests to insure satisfactory performance and reliability under rated thrust conditions. These tests were conducted on the interim test stand at the Marshall Space Flight Center (MSFC). A total of 32 static tests were conducted on the MERCURY and test boosters with an accumulated

time of over 2230 seconds. In addition to the basic static firing tests to assure proper assembly and operation of the propulsion unit, additional tests were run to derive both additional data and help solve specific problems.

### 6.2.3.2 Capsule Noise and Vibration Tests

Noise and vibration effects on the missile and capsule were evaluated early in the program in a series of four test firings in the static test tower using a boilerplate capsule. The results, shown in Table 6-1, indicate these environment conditions were not detrimental to the booster or capsule.

Table 6-1

Sound and Vibration During Static Firing

| Location | Sound Pressure Level at 1000 cps (db) | Composite Vibration at Mainstage Thrust - peak g | | |
|---|---|---|---|---|
| | | Lateral | Longitudinal | Pitch |
| Tail Fin | 141 | | | |
| Outside Capsule | 123 | | | |
| Inside Capsule | 101 | | | |
| Escape Rocket | 123 | 2 | 1 | 2 |
| Capsule Adapter | | | 4 | 4.3 |
| Instrument Comp. (TV Camera) | | | 1.5 | |
| Fuel Tank | | 4.5 | 4.5 | |
| Thrust Frame | | 4.5 | 6.5 | 8.2 |

### 6.2.3.3 Hydrogen Peroxide System

Subsequent to the static firings of MR-1 and MR-2, a major redesign of the $H_2O_2$ system was effected. The redesign required O-ring seals in lieu of metal-to-metal seals in the system. The results of the tests conducted during the static firing of MR-3 indicated the O-rings to be functioning properly and, therefore, satisfactory for flight. The O-rings also appeared to be compatible with the heat produced by $H_2O_2$ system heater blankets, which were also part of the modifications.

#### 6.2.3.4 Oscillation Problems

When MR-4 was static fired the first time, an unexpected low frequency oscillation (approximately 10 cps) was discovered in the oscillograph traces of the engine parameters. This oscillation had not been present during the static firings of the previous boosters. A thorough investigation revealed that the oscillations were the result of resonance of the test stand with the second bending mode of the booster when the booster was mounted from the top of the stand. The modification to the stand, subsequent to the MR-1 and MR-2 tests but prior to the MR-3 test, had changed the resonant frequency of the stand. MR-3 did not resonate because it was attached in a different manner. Modification to the stand prevented this resonance.

#### 6.2.3.5 Boattail Heater Tests

In tests simulating the actual launch countdown, LOX was loaded several hours prior to ignition. To maintain all engine parameters and critical temperatures within specified limits during the hold period, hot-air-type heater ducts were inserted through the access doors into the boattail section. During the series static firings, hold periods as long as eight hours were successfully made without adverse affects.

#### 6.2.3.6 LOX Manhole Cover Seal Leaks

When several LOX leaks occurred in the LOX tank manhole cover seal of various REDSTONE vehicles, a test program was initiated to determine the cause and characteristics of the leaks. Compression of the cover gasket was approximately 0.012 inch greater using lubricated bolts than when nonlubricated bolts and washers were used at the same torque values. However, complete sealing was not achieved in any test, even with the cover bolt tightened to 190 inch-pound torque using no lubricant.

#### 6.2.3.7 LOX Replenishing Tests

In a further effort to simulate actual launch conditions, the LOX replenish system was tested to determine its capability to maintain the required LOX level during extended hold periods. No difficulties were experienced with the system.

#### 6.2.3.8 Abort Sensors

A problem was encountered in the early phase of testing when water (used in the inert start) was blown into the two abort combustion chamber pressure ($P_c$) sensing lines and the single thrust controller transducer $P_c$ line. The low LOX temperatures then

froze the water preventing proper operation of the sensors. This difficulty was solved by the utilization of strip heaters on all three lines.

### 6.2.4 ALIGNMENT TEST (MECHANICAL)

After static firing and before the integrated mechanical-electrical checkout tests, mechanical alignment checks were performed on the power unit, the tail section, the aft unit, and, finally, on the entire thrust unit. All six boosters successfully completed their alignment tests; however, four problem areas occurred during this checkout. The test plan included a capsule adapter mating alignment check. Since none of the adapters were available at the time of the alignment tests, only the mating surfaces were checked. Difficulty in assembly of the jet vane plates caused the plates on MR-1 and MR-3 to be off in perpendicularity. On MR-2 and -8 the plates were off in angularity. These discrepancies were minor and were waived. The first three vehicles required shimming of the engine. MR-1 and -2 were shimmed because the mounting holes would have otherwise been too close to the edge of the mounting ring. MR-3 was shimmed and MR-1 additionally shimmed to correct for thrust vector misalignment.

### 6.2.5 PRESSURE AND FUNCTIONAL ANALYSIS

Pressure and functional analysis tests were performed to assure correct operation of the pneumatic and hydraulic systems of the vehicle. All systems on all vehicles were within limits. Actually, two sets of pressure and functional tests were made; the first immediately after the alignment tests and the final before booster shipment to the launch site. Vehicles MR-3, -5, -7, and -8 were shipped with 10 psig air pressure in the gaseous nitrogen spheres.

### 6.2.6 CONTINUITY TESTS (ELECTRICAL)

Electrical assembly and installation and ground support equipment compatibility were checked. All vehicle connectors and cables were inspected, and resistance measurements were made on all wire to assure that continuity existed. In addition, all vehicle distributors and the ground support equipment were verified prior to connecting to the vehicle. Several installation discrepancies were revealed in MR-2, -3, -5, -7, and -8, all of which were corrected prior to release of the vehicle. After correction of these discrepancies, the test results were satisfactory.

## 6.2.7 NETWORK TESTS

### 6.2.7.1 Introduction

This group of tests performed on the vehicle were given the general classification of network tests and consisted of the component test, cutoff test, and over-all Test No. 1. It was in this group of tests that the electrical location of relay contacts, diodes, and solenoids were ascertained from comparison with the vehicle schematics.

### 6.2.7.2 Component Tests (Propulsion System Electrical Network)

The component tests were designed to verify proper operation of components associated with the propulsion system operation. This test was performed in two parts. The first part, performed without pneumatic pressure, verified the electrical location and operation of propulsion-control relays and valve solenoids. For safety reasons, special attention was given to the control circuits for pressurizing and venting the high pressure pneumatic spheres. The second part, performed with pressure applied to the spheres, checked the operation of pneumatic valves and valve position switches. The component tests verified that all components associated with the propulsion engine operation were satisfactory on all six vehicles.

### 6.2.7.3 Cutoff Test (Shutdown and Abort System Networks)

The cutoff test was not limited to verification of the vehicle cutoff circuitry as the name implies, but actually entailed extensive testing of the abort circuits, destruct command receivers, and flight sequencer operation. In addition, the television on-off command and the circuitry for shifting the television lens cover were verified up to the point of entry into the television junction box and camera assembly. The cutoff tests on MR-1, -7, and -8 were completed satisfactorily. While verifying proper operation of the MR-3's electrical network, two diodes and a relay were found to be faulty. In addition, two shorting pins in a ground equipment connector were causing the inverter to malfunction. Replacement of the faulty parts eliminated these problems. Vehicle MR-5 had satisfactory results; however, during the test it was necessary to replace a relay in the GSE test conductors panel, as a result of the failure of one of its contacts.

### 6.2.7.4 Over-all Test No. 1 (Sequential Flight Simulation)

An over-all test is defined as a test in which, as a minimum, a switch-on sequence is performed, followed by a transfer from ground to vehicle internal power, a rocket engine firing sequence, a simulation of liftoff, and a rocket engine cutoff signal is

given. Over-all test No. 1, the third network test, was designed to test the sequential operation of the valves, relays, and solenoids involved in the engine firing; also tested were the program device, flight sequencer, and physical separation of the top and tail umbilicals.

During the over-all test No. 1 on MR-1 and MR-2, trouble was encountered with the preflight cooling system operation and circuitry, which was corrected by replacement of components and rewiring. As a result, later $LN_2$ external cooling systems were required to pass a checkout simulation prior to the over-all test. A false abort was indicated during MR-2's over-all test. The exact initiator of the abort could not be identified, but the rate switch circuitry was suspected. A redesign of this circuit was made to eliminate any possible cause. The program device was found to be faulty on MR-3. MR-5, -7, and -8 passed over-all test No. 1 satisfactorily.

### 6.2.8 RADIO FREQUENCY SYSTEMS CHECKOUT

These tests were performed to insure that each RF component operated properly within specified limits during individual functional checks. In addition, the tests verified that the RF components were compositely compatible with themselves and with the general network. Interference was encountered when MR-2 and MR-5's television circuits were in a standby mode. However, during normal operation the television oscillator frequency radiation dropped to a noninterference level.

### 6.2.9 CONTROL SYSTEMS CHECKOUT

The control system checkout was performed to ascertain the function of the system as it related to the vehicle performance requirements. Controlled inputs were introduced into the system, and the outputs were accurately checked for proper polarity and scale factors. MR-1, -2, -3, and -5 tested satisfactorily. Replacement of faulty attitude error sensor was necessary on MR-7. Dust in the pitch attitude sensor of MR-8 required cleaning of the sensor before final acceptance.

### 6.2.10 OVER-ALL TEST NO. 2

This test was performed to assure proper functioning of the vehicle's control system integrated into the general network. The test sequence was similar to that of over-all test No. 1 but with the addition of the control system. The results of over-all test No. 2 were completely satisfactory for all vehicles.

### 6.2.11 INSTRUMENTATION CALIBRATION

Signal outputs from the various measuring transducers were first checked to calibration curves via hardwire link; then, the information was connected to the telemetry package and rechecked via RF link. The results of the instrumentation and calibration tests on MR-1 and MR-2 were completed satisfactorily. The remaining vehicles had several minor problems none of which indicated a specific problem area.

### 6.2.12 OVER-ALL TEST NO. 3

In this test the control, RF, and instrumentation subsystems were integrated and tested as a complete system. The test consisted of a brief subsystem operational check and then a complete simulated firing and flight sequence. The vehicle was put in a ready-to-fire condition, firing command was given, and the sequence of events that followed was automatic until liftoff. Liftoff was simulated by de-energizing the tail plug supervision relays in the ground equipment and the liftoff relays in the vehicle. This method of simulating liftoff allowed continuous monitoring and recording of vehicle operation during the simulated flight period. After liftoff, the program device controlled the operation of the flight sequencer, the telemeter calibrator, and the tilt program of the LEV-3. The vehicle was then given a normal cutoff from the velocity integrator, and, shortly thereafter, the test was completed by simultaneously removing all power from the vehicle and ground equipment. Vehicles MR-1, -2, -3, and -5 completed the tests with satisfactory results. MR-7 encountered a broken lamp contact in the ground propulsion panel. Additional shield grounding was required to eliminate erratic pulses on MR-8's program device channel No. 1.

### 6.2.13 SIMULATED FLIGHT TESTS

This final test of the booster was designed to prove the compatibility of all electrical and electro-mechanical systems (vehicle and ground equipment) in simultaneous operation. Safety-relay boards were installed in the main, tail, and power distributors to make this test more realistic. The test was performed using a simulated countdown procedure. Preliminary checks were made in which the vehicle subsystems were energized and operationally verified. The vehicle was then placed in a ready-to-fire condition, and the firing command was given. The vehicle underwent a typical flight program, controlled by the program device, with small deviations from the normal trajectory simulated by the tilt program of the LEV-3. At liftoff plus 140 seconds, cutoff was given by the velocity integrator, and 30 seconds later the test was terminated by simultaneously removing power from the vehicle and the ground equipment.

Since the vehicle's instrumentation was active during the test, its telemetered information was utilized for evaluation.

MR-1 and -3 passed successfully. MR-2 had problems with foreign material causing shorts in the commutated telemeter channels. MR-5 had flight sequencer problems which were solved by redesign and removal of two zener diodes. The roll rate gyro was also defective and was replaced, as was the thrust controller transducer. MR-7 was rerun twice before the proper procedures were used and MR-7 passed. The pitch attitude potentiometer had to be cleaned and the pitch rate switch replaced before MR-8 passed its simulated flight test.

### 6.2.14 RETEST AFTER MODIFICATION

After the test program had progressed through the simulated flight test, a number of changes to assure the best possible boosters were incorporated. After making these changes, the systems affected were rechecked to verify proper operation. The most extensive modifications were made on MR-5; thus, the MR-5 checks consisted of a continuity test of new and modified cables, a series of network tests which verified proper operation of the vehicle's electrical circuitry, measuring and control systems check, and an operation verification of the RF equipment. An over-all test was then performed to verify proper operation of the network, control, RF, and measuring system. In-flight measurements were telemetered to verify calibration of the measuring system. Proper operation was obtained during these tests.

### 6.2.15 BOOSTER-CAPSULE COMPATIBILITY TESTS

The original test plan included mating each capsule plus its GSE to the booster and its GSE at MSFC for a final compatibility test prior to shipment to the launch site. The compatibility tests were to include electrical continuity, RF, separation, abort system, and an over-all test. On MR-1 several compatibility problems (noted below) were encountered; however, MR-2 tests experienced no new compatibility difficulties. Therefore, for vehicles MR-3 through MR-8 only the capsule adaptors were mated and tested.

Compatibility measurements on the Booster MR-1 and its GSE indicated that the MAYDAY circuit from the vehicle GSE to the capsule would allow a high current flow and could possibly prevent completion of the abort sequence. To assure launch director abort capability, a diode was added to the capsule circuitry. During the final RF checkout on MR-1 and -2, the booster's DOVAP signal interfered with the capsule's

two command receiver signals. A change in command frequency and removal of the booster DOVAP eliminated this interference. Also during the mating, the clamp ring retention devices were found to be incorrectly designed and were redesigned by MSFC. Lastly, electrical connectors and wire bundles from the booster to the adapter could not be properly installed. Relocation of the connectors and removal of the recovery system package solved these interface problems.

## 6.3 SPECIAL RELIABILITY TESTS

### 6.3.1 GENERAL

In addition to the developmental tests, several special reliability test programs were conducted to attain the degree of assurance required by the manned payload. These tests were conducted as a portion of the over-all reliability, quality control, and check-out program.

### 6.3.2 THRUST UNIT STRUCTURE

Structural testing of the thrust unit was done in three separate tests:

- Simulated flight loads were imposed on the vehicle to 150 percent of the nominal value on the tail and center sections to determine the margin of safety. Combined axial compression, shear, and bending loads (Figure 6-2) were applied without resulting damage. In addition, the propellant tanks were pressurized until they burst. The tests were conducted in a vertical test tower.
- Fin and rudder test determined the tail unit's capability to withstand flight and handling loads exceeding 150 percent of the design values.
- Ground handling tests determined that there were no detrimental effects when bending, shear, and axial compression loads, equaling 150 percent of design values, were applied to the forward and aft handling fixtures.

### 6.3.3 AFT SECTION

An aft section, MRF1, containing the guidance and control system, the abort system, telemetry, and the instrument compartment cooling system was subjected to temperature and vibrational environments in a special test setup known as the "rock and roll" stand, Figure 6-3. Testing was divided into three phases.

- Phase I - Flight motions and vibrations were imposed at ambient temperatures in seven cycles, Figure 6-4. Outputs of the systems under test

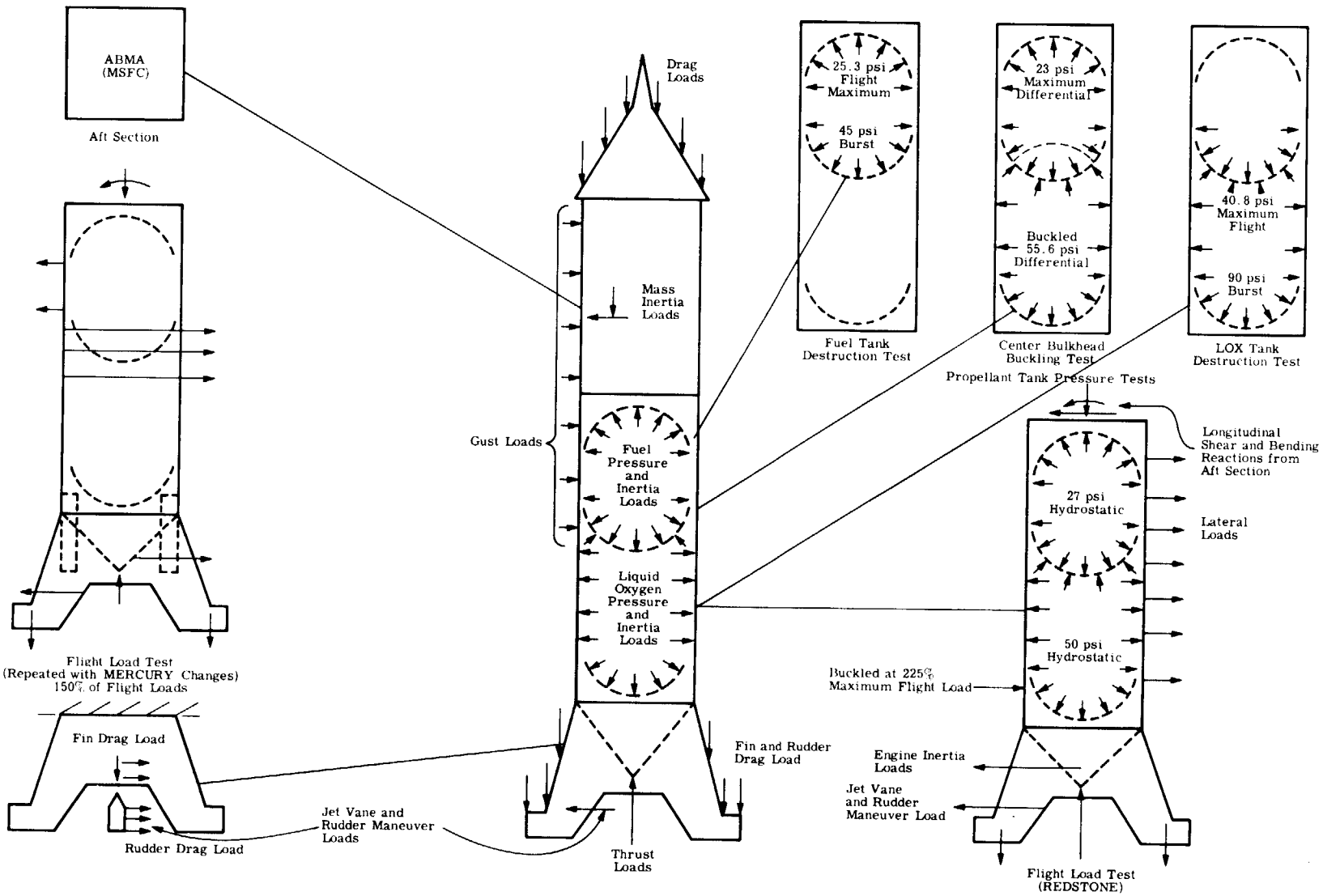



Figure 6-2. Flight Environment of Thrust Unit

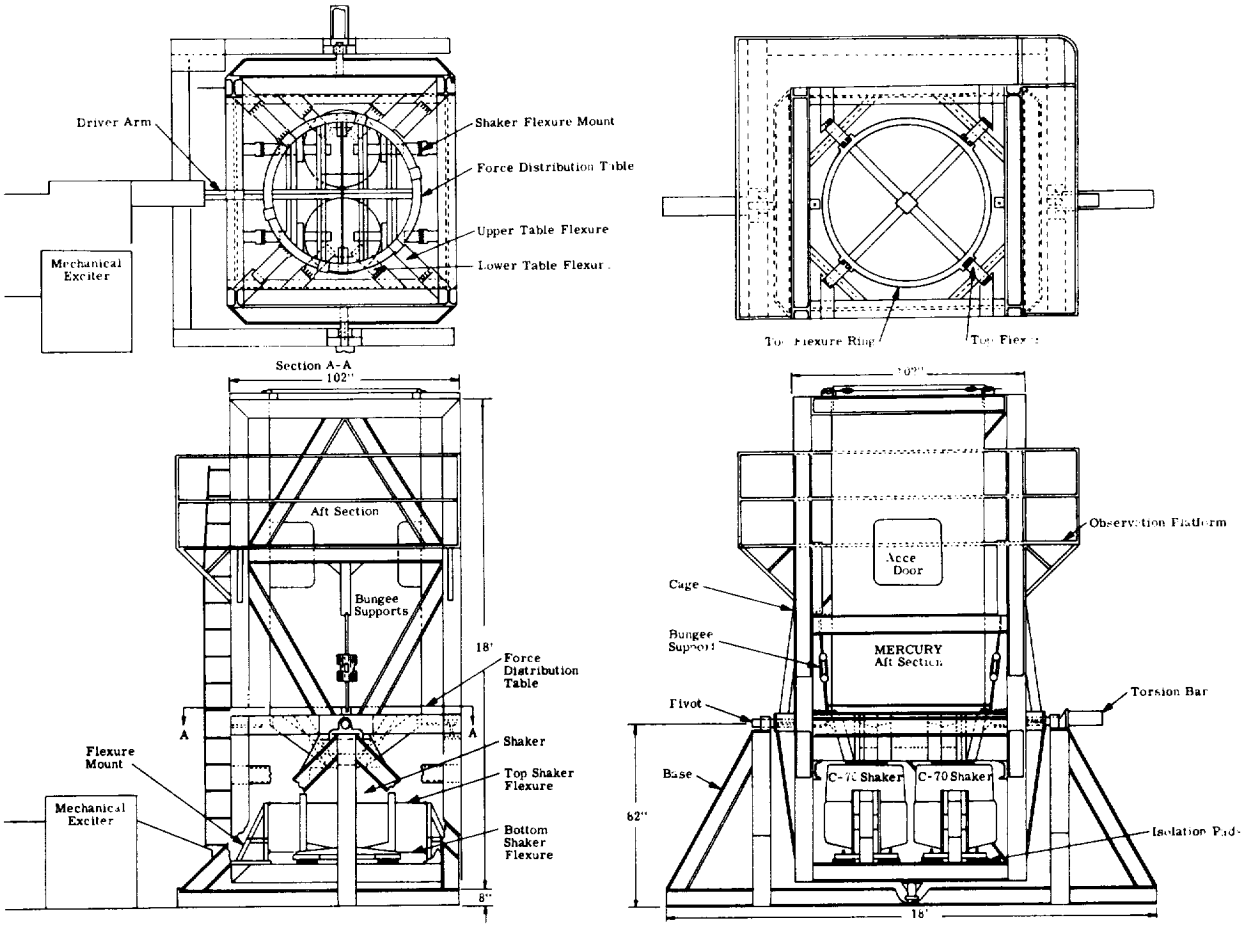



Figure 6-3. Vertical Test Fixtures

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Phase I<br>Flight Vibration and Motion<br>Object: To Subject A REDSTONE MERCURY Aft Section To The Vibration Most Likely Encountered During Flight | CYCLE I<br>$1_g$<br>20-2000 cps<br>Sweep Time<br>50 Sec & 20 Sec<br>Ambient Temp | CYCLE II<br>$1_g$<br>20-2000 cps<br>Sweep Time<br>50 Sec & 20 Sec<br>Ambient Temp | CYCLE III<br>$1_g$<br>20-2000 cps<br>Sweep Time<br>50 Sec & 20 Sec<br>Ambient Temp | CYCLE IV<br>$1_g$<br>20-2000 cps<br>Sweep Time<br>50 Sec & 20 Sec<br>Ambient Temp | CYCLE V<br>$1_g$<br>20-2000 cps<br>Sweep Time<br>50 Sec & 20 Sec<br>Ambient Temp | CYCLE VI<br>$1_g$<br>20-2000 cps<br>Sweep Time<br>50 Sec & 20 Sec<br>Ambient Temp | CYCLE VII<br>$1_g$-$2_g$-$3_g$-$4_g$<br>20-2000 cps<br>Sweep Time<br>3 Minutes<br>Ambient Temp |
| Phase II<br>Instrument Compartment Cooling<br>Object: To Determine The Capability of the External Cooler To Cool and Dry The Instrument Compartment. The Effect Of This On The Inverter Brushes Will Also Be Determined. | Temperature<br>70-75 ° F<br>Relative Humidity<br>85 to 90 % | Temperature<br>85-90° F<br>Relative Humidity<br>85 to 90 % | Temperature<br>110-115°F<br>Relative Humidity<br>70 to 75 % | Temperature<br>110-115° F<br>Relative Humidity<br>70 to 75% | | | |
| Phase III<br>Transportation And Pad Temperatures<br>Object: To Determine If The Temperatures Encountered During Transportation And Stand-By On The Pad Will Effect The Systems Operation. | TEMP<br>0° F and<br>125°F | TEMP<br>0° F and<br>125° F | TEMP<br>0°F and<br>125° F | | | | |

Figure 6-4. Aft Section Test Summary

were continuously recorded and indicated intermittent operation of the pitch program and the pitch and yaw rate switches. During the seventh cycle when the loads exceeded design values, the telemetry commutator intermittently failed, and a command receiver pitch rate switch and one computer output channel failed. All malfunctions were corrected prior to flight qualification. A subphase test, the abort systems test, determined that the proper abort signals were given when the abort pitch and yaw rate switches were oscillated (rocked) and the voltage to the control voltage sensor was stepped below the abort limit.

- Phase II and III - Instrument compartment cooling and transportation and pad temperature tests (Figure 6-4) were completed without discrepancies.

### 6.3.4 PROPULSION SYSTEM

The propulsion system's fill and vent valves, suction lines, and rocket engine were simultaneously vibration and temperature tested in a combined environment chamber. The temperatures ranged between -10°F and 125°F (the LOX system was tested at $LN_2$ temperatures). Imposed vibrations up to 20 g's were swept between 20 and 2000 cps. Table 6-2 lists the results of this test.

### 6.3.5 TAIL SECTION

A MERCURY-REDSTONE tail section, RMF73, containing all mechanical and pneumatic systems were vibration and temperature tested under similar conditions imposed on the propulsion system. The results of this test are given in Table 6-3.

### 6.3.6 CAPSULE-BOOSTER COMPATIBILITY

A 36-day checkout of the physical and functional compatibility of the capsule and booster was made on MR-1 and MR-2 at MSFC. This checkout was part of the development tests described in paragraph 6.2. For vehicles MR-3 through -8, the capsule compatibility was checked at the launch site and only the flight adapter-booster compatibility checked at MSFC. These over-all checkouts were of great value in achieving the reliability demonstrated by the MERCURY-REDSTONE.

### 6.3.7 ABORT SYSTEM

An abort system test program was conducted to assure the proper and reliable functioning of the automatic abort system. The tests and their results are detailed in paragraph 5.4.

Table 6-2

Propulsion System Test Results

| Component | Failure Level | Failure | Corrective Action |
|---|---|---|---|
| Engine: | | | |
| Regulator | 125°F 1g | Pressure Varies | All Regulators Flow Tested |
| Fuel Duct Support | 125°F 3g | Weld Cracked | 100 Percent Inspection |
| Main Fuel Valve | 125°F 5g | Main Shaft | Failure Attributed to Procedure |
| Tube Clamp $H_2O_2$ Line | 2g Resonance | Clamp Failed | Additional Clamp Added |
| $H_2O_2$ Tank Bracket | 2g Resonance | Weld Failure | Leakage Slight After Test Complete - No Action |
| Steam Generator | 0°F 5g | Weld Failed | Additional Support Added |
| Auxiliary $H_2O_2$ Tank | 125°F 3g | Support Failed | Modified Design for Additional Support |
| Steam Exhaust Duct | 2g Resonance | Deformed | No Rupture - No Action Required |
| Thrust Control Amplifier | 2g Resonance | Lock Nuts Loose | Inspect Locknuts - No Design Action |
| LOX Fill System | 12g | Valve Leakage | Acceptable |
| LOX Vent System | 12g | Valves Failed | Modification not Warranted |
| Fuel Vent System | | Weld Failed | Added Support on Pressure Line |

Table 6-3

Tail Section Test Results

| Item | Failures | Remarks |
|---|---|---|
| Triple Sphere Support Bracket | Major Failure of Support Bracket | Redesign bracket tested during second phase of test with only minor failure - larger rivets used in final design. |
| Single Sphere | Abrasion of Support Bracket | Pad incorporated in design |
| | Cracks in Support Structure | Not considered a major discrepancy |
| Pneumatic System | None | Design Acceptable |

## 6.4 MASS DAMPENING OF INFLIGHT VIBRATIONS

### 6.4.1 GENERAL

After the second successful flight, MR-2, a program was initiated to reduce the vibrational environment of the instrument compartment where vibration sensitive components were located. Since the major sources of excitation in this area were the acoustic environment at launch and the aerodynamic turbulence during flight, due to the change in the diameter of the spacecraft relative to that of the booster, the primary approach was to reduce the energy absorbed by the structure by mass dampening of the panels that were subjected to the excitation environment.

### 6.4.2 METHOD OF MASS-DAMPENING

The first step in an effort to reduce the vibrational environment was a program to develop a viscoelastic material of high specific gravity which would be easily applied. A mass dampening compound, X306, was developed by the Materials Branch at MSFC. The material was a mixture of lead chips (60 to 70 percent by volume) in epoxy polysulfide. Figure 4-24 illustrates the vehicle areas to which the compound was applied.

On MR-BD, 170 pounds of the material were applied to the inner sides of the skin panels in the bays of the recovery compartment and 40 pounds were applied to the

upper bulkhead of the instrumentation compartment proper. This made a total of 210 pounds applied to MR-BD.

In MR-3, the material was not only applied to the above areas but also 120 pounds were applied to all the access doors of the instrumentation compartment making a total of 330 pounds applied to MR-3.

The material was applied to the doors, the lower bulkhead, and all the accessible panels of the instrumentation compartment of MR-4 as well as the recovery compartment for a total of 405 pounds. The total amount of mass dampening material applied to the instrumentation compartment proper of MR-4 was 235 pounds. The application of the mass dampening material to this latter area had the most significant effect on the vibrational environment, and it is felt that the 235 pounds applied to the instrumentation compartment would have been sufficient.

### 6.4.3 VIBRATIONAL MEASUREMENTS

#### 6.4.3.1 Introduction

On each flight at least two vibration transducers were installed in the aft unit of the vehicle to measure the vibrational environment during powered flight. Measurement 901 was mounted on the adapter ring and was oriented to measure vibration in a direction perpendicular to the longitudinal axis of the vehicle. This measurement was made on every flight. Measurement 903 was located on the rate gyro mounting bracket and was oriented to measure vibration in the longitudinal direction of the vehicle. When the MR-1A vehicle overshot the target area, measurement 903 was moved to a new location on the LEV-3 velocity cutoff platform and was designated as measurement 906. The sensitive axis of the accelerometer remained oriented in the direction of the longitudinal axis of the vehicle. Measurement 906 was then flown on each of the subsequent flights. Measurement 950 was a low frequency transducer and was oriented to measure body bending oscillations in the yaw plane perpendicular to the longitudinal axis of the vehicle. This measurement was flown only on MR-BD.

The approximate locations of the various transducers are shown in Figure 6-5. Table 6-4 indicates on which flight the various vibration measurements were flown and the calibration level of the measurement.

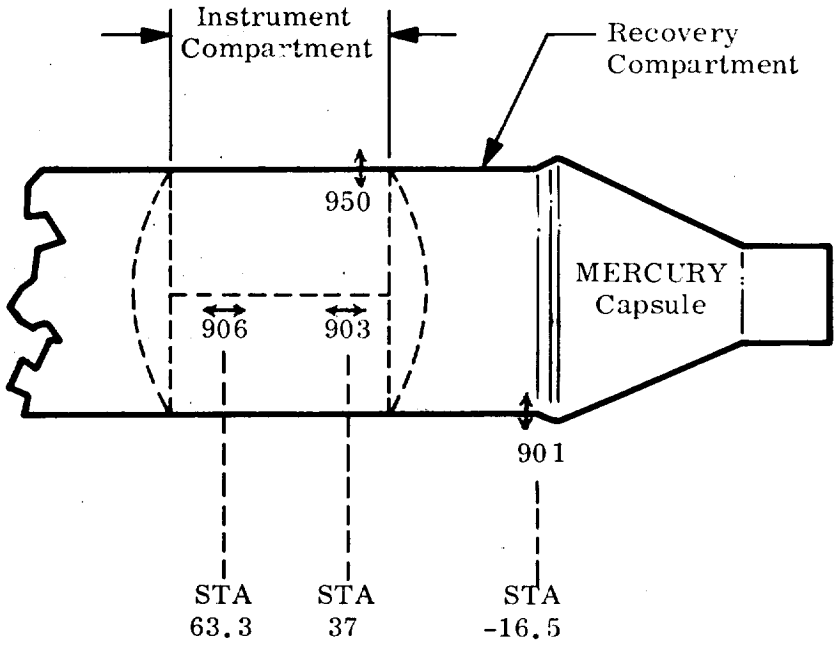



Figure 6-5. Location of Instrument Compartment Vibration Transducers

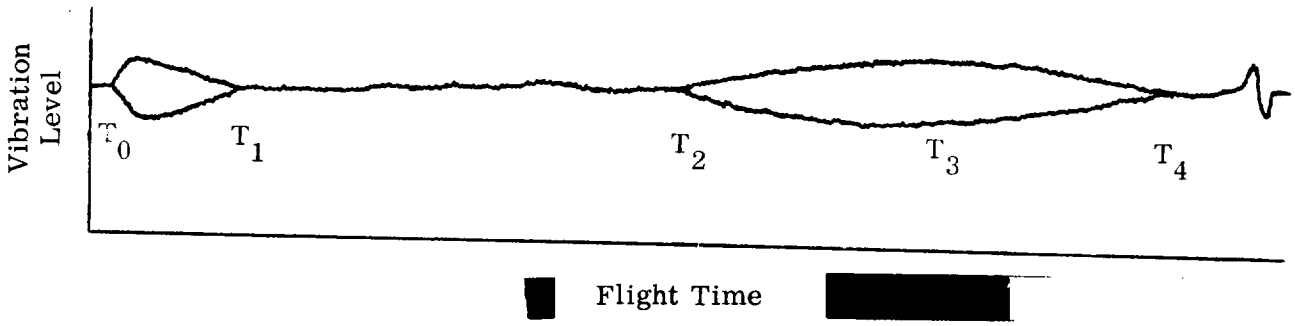
Table 6-4

Flight Vibration Measurements

| Measurement No. | Calibration Range | | | | |
|---|---|---|---|---|---|
| | MR-1A | MR-2 | MR-BD | MR-3 | MR-4 |
| 901 | ±3g | ±6g | ±12g | ±30g | ±30g |
| 903 | ±3g | | | | |
| 906 | | ±6g | ±8g | ±8g | ±10g |
| 950 | | | ±0.5g | | |

6.4.3.2 Measurement 901

The general characteristics of measurement 901 are shown in Figure 6-6. The composite measurement indicates a sharp increase in the vibration level immediately after




Measurement 901 Vibration Capsule Mounting Ring-Lateral

| Flight Number | $T_1$ Time Liftoff Vibration Ends | | $T_2$ Amplitude Increase Starts Seconds | $T_3$ Max. Amplitude Reached | | $T_4$ Time Vibration Returns to Low Level Seconds |
|---|---|---|---|---|---|---|
| | Time Sec. | Max. Mag. G's PK/PK | | Time Sec. | Max. Mag. G's PK/PK | |
| MR-1A | 12 | * | 28 | 65 | * | 135 |
| MR-2 | 10 | * | 24 | 68 | * | 130 |
| MR-BD | 7 | 29.7 | 37 | 70 | * | 130 |
| MR-3 | 5 | 30 | 47 | 70 | 58 | 120 |
| MR-4 | 6 | 23.6 | 43 | 70 | 52.4 | 122 |

* Measurement System Capabilities Exceeded

Figure 6-6. General Characteristics of Vibration Measurements (901)

ignition ($T_0$) and during liftoff. The vibration energy for this phase is due mainly to the acoustic environment created by the engine. The level then decreases to a very low magnitude ($T_1$) until such time ($T_2$) as the aerodynamic turbulence becomes strong enough to excite the structure after which the level gradually increases to a maximum ($T_3$) at approximately 70 seconds, when Mach 1 occurs Thereafter, it decreases gradually to a negligible magnitude ($T_4$) and remains so until cutoff and separation where a normal transient occurs.

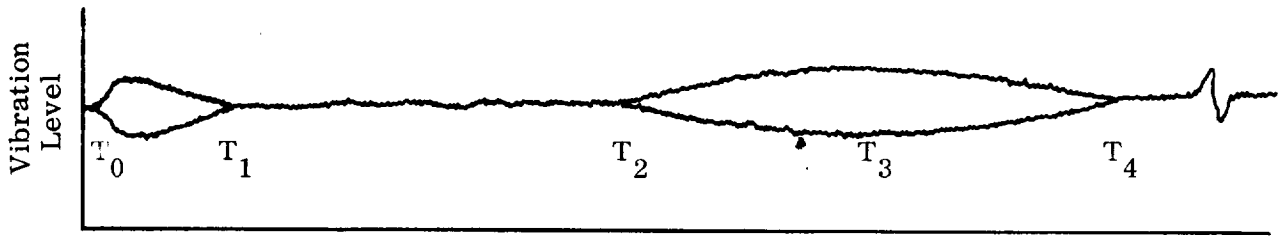
All the trajectories flown were similar except for MR-1A. It is, therefore, valid to compare the measurements made in one flight against those of another. The tabulated information in Figure 6-6 shows the various times and magnitudes of the different characteristics explained above. The magnitude of the vibration levels was lowered only slightly indicating that the material had little effect as far as measurement 901 was concerned. This, however, is to be expected since 901 was mounted on a substantial structure, the adapter ring.

6.4.3.3 Measurement 906

The general characteristics of measurement 906 were very similar to those of 901 and are shown for the various flights in Figure 6-7. Since this measurement was mounted on substructure in the instrumentation compartment proper, it is logical that it was affected the most by the application of the mass dampening compound. By comparing the magnitudes experienced in the MR-4 flight with those of the earlier flights, it was observed that the magnitude decreased by a factor of approximately 3. Since both the measurements were saturated in flights MR-1A and MR-2, no definite comparison was made to the latter flights.

6.4.4 VIBRATIONAL CHARACTERISTICS

The duration of the increase in vibration levels due to the aerodynamic turbulence decreased from approximately 80 seconds to 54 seconds, as the amount of mass dampening material was increased in the instrumentation compartment. The addition




Measurement 906 Vibration LEV-3 Base Plate

| Flight Number | $T_1$ Time Liftoff Vibration Ends | | $T_2$ Amplitude Increase Starts Seconds | $T_3$ Max. Amplitude Reached | | $T_4$ Time Vibration Returns to Low Level Seconds |
|---|---|---|---|---|---|---|
| | Time Sec. | Max. Mag. G's PK/PK | | Time Sec. | Max. Mag. G's PK/PK | |
| MR-1A[1] | 10 | * | 40 | 70 | * | 120 |
| MR-2 | 4.5 | * | 38 | 65 | * | 115 |
| MR-BD | 5 | 13.8 | 50 | 69 | 21.8 | 115 |
| MR-3 | 4 | 14 | 48 | 70 | 18 | 117 |
| MR-4 | 5 | 4.2 | 56 | 71 | 6.2 | 110 |

1 - Measurement 903 (Vibration Switch, Rate) used here For Comparison because 906 was not flown on MR-1A.

* - Measurement System Capabilities Exceeded.

Figure 6-7. General Characteristics of Vibration Measurements (906)

of dampening compound, therefore, had two beneficial effects. It lowered the amplitude of the vibration levels, and it shortened the time the critical flight components were subjected to substantial vibration levels.

The vibration environment of the instrumentation compartment was the most severe at Mach 1. Typical vibration spectra for this flight time are shown in Figure 6-8. The spectrum indicates that the majority of the energy lies in the frequency region from approximately 600 to 1200 cps and did not change appreciably from flight to flight. The final spectra of MR-4 was almost flat indicating that there was no appreciable response of the substructure of the instrumentation compartment.

## 6.5 BOOSTER RECOVERY SYSTEM DEVELOPMENT

### 6.5.1 GENERAL

One of the more interesting, yet least well-known, aspects of the MERCURY-REDSTONE Project was the design, development, and full-scale testing of a recovery system which

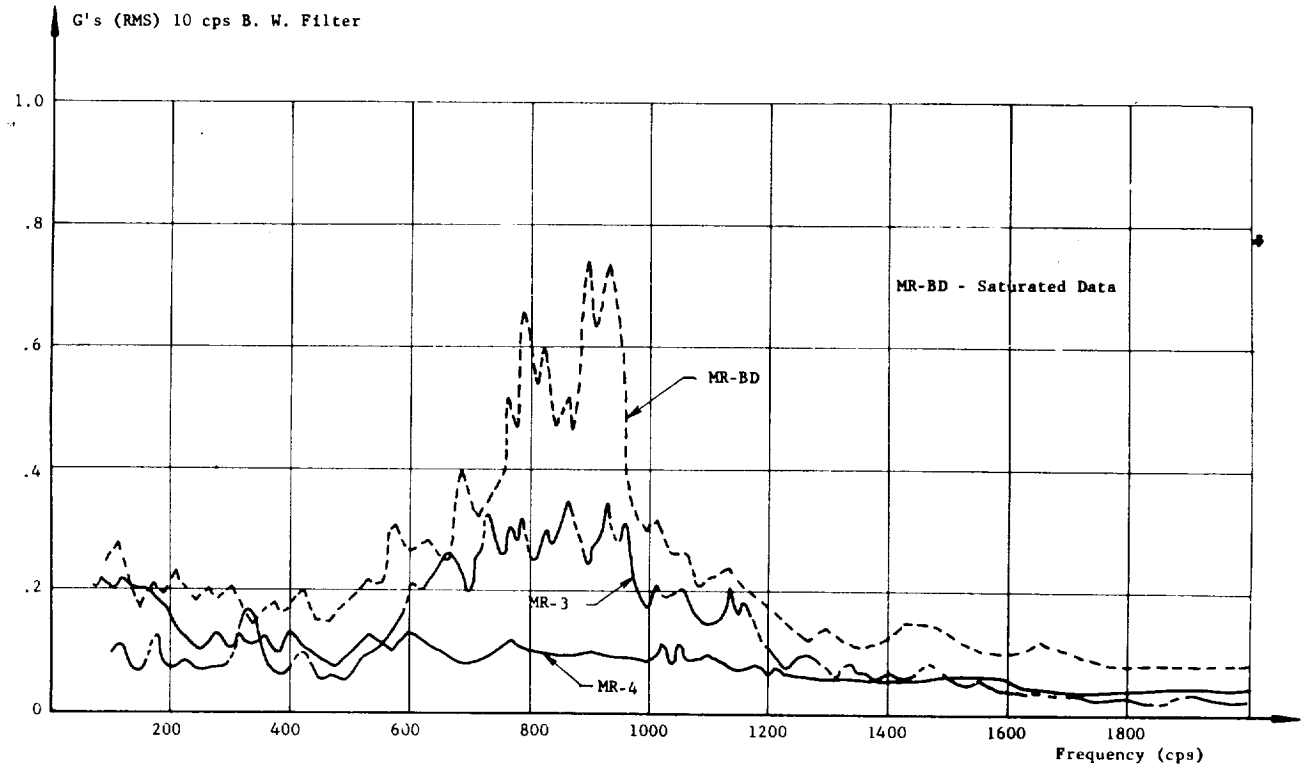



Figure 6-8. Longitudinal Vibration Spectra for MERCURY-REDSTONE Vehicles

would permit reuse of the booster. This project was the first extensive development of a recoverable booster and would have actually been implemented if that portion of the program had not been cancelled because of a lack of funds.

Recoverable boosters and the systems required for such recovery are still of interest today. Present operational analyses indicate that the economics of extensive space operations may necessitate the utilization of the recoverable concept for launch vehicles. Preliminary design studies are already determining the feasibility of recovering large boosters such as the S-IC stage of the SATURN V launch vehicle. As a consequence, the MERCURY-REDSTONE recovery investigations are of significance due to both the technical results achieved and the fact that it was the first such study to be carried through to actual full-scale testing of development hardware.

Although none of the boosters subjected to water impact tests were static fired, sufficient checkout of the propulsion systems was made to determine that they were functional after water immersion. In addition, extensive sea water immersion trials were conducted on a Rocketdyne H-1 engine which was successfully static fired several times following the trials. The general conclusion reached was that sea water impact and immersion would not prevent successful reuse of the booster after cleaning and checkout.

The MERCURY-REDSTONE Program lent itself to a booster recovery development program because of several factors:

- Recovery system space was available.
- The required ballast weight could be replaced with a recovery system, thus lessening the recovery system weight penalty on the primary mission of the booster.
- The REDSTONE booster structure had good strength and flotation characteristics for parachute recovery and landing in water.
- Booster stability problems were as severe during the parachute deployment phase as those which may be expected in future programs.
- Recovery weight was within the state of parachute design, yet high enough to outline areas where future problems may exist.
- Over-all size and weight of the REDSTONE allowed water recovery without extensive modification to available ships and handling equipment.

### 6.5.2 DESIGN REQUIREMENTS

REDSTONE booster structural data which influenced recovery system design were:

| | |
|---|---|
| Booster weight (dry) | 15,000 pounds |
| Booster diameter | 70 inches |
| Booster length | 700 inches |
| Maximum load (longitudinal) | 8 g |
| Maximum load (lateral) | 3 g |
| Water impact velocity | 40 feet per second (maximum) |

The trajectory considerations which influenced recovery system design are given in the following paragraphs.

Booster re-entry attitude was not predictable; the booster could be stable at any angle of attack, spinning, or tumbling at first stage parachute deployment. As a result of the undefined booster attitude, time of flight to impact could vary for a given trajectory. The altitude at which the booster would decelerate to a subsonic velocity could vary between 65,000 feet and 20,000 feet, depending on angle of attack and stability. Therefore, aerodynamic means of sensing velocity or altitude were not suitable for first-stage parachute deployment initiation.

There could be a variation in the cutoff signal of up to ±8.7 seconds in order to meet the required cutoff conditions in the planned trajectory. These variations were due to variations in engine burning time, mixture ratio, and wind shear effects during powered flight. This range of about 17 seconds prevented use of a program timer for primary recovery system sequencing with a subsonic first-stage parachute deployment.

### 6.5.3 RECOVERY SYSTEM DESIGN

#### 6.5.3.1 Introduction

The recovery system consisted of a g sensitive switch, a sequencing system, a system to initiate a deployment system, a two-stage parachute system, parachute containers, a structure to distribute the parachute forces into the booster, heat protection, and an instrumentation system to furnish information about recovery system operation to the booster telemetry system. The recovery system was packaged in a self-contained unit. Figures 6-9 through 6-12 illustrate the operation of the recovery system.

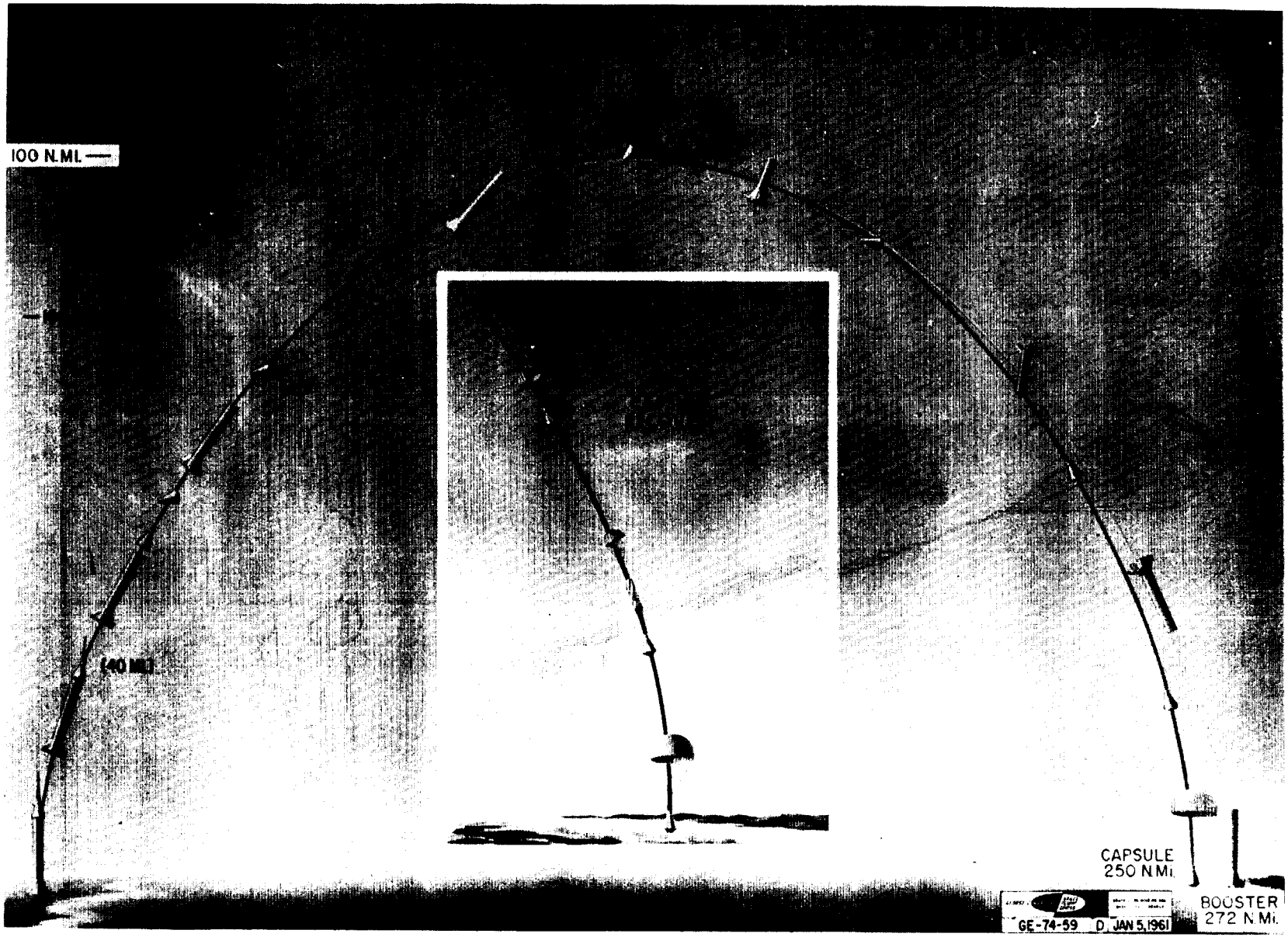



Figure 6-9. MERCURY-REDSTONE Flight Sequence

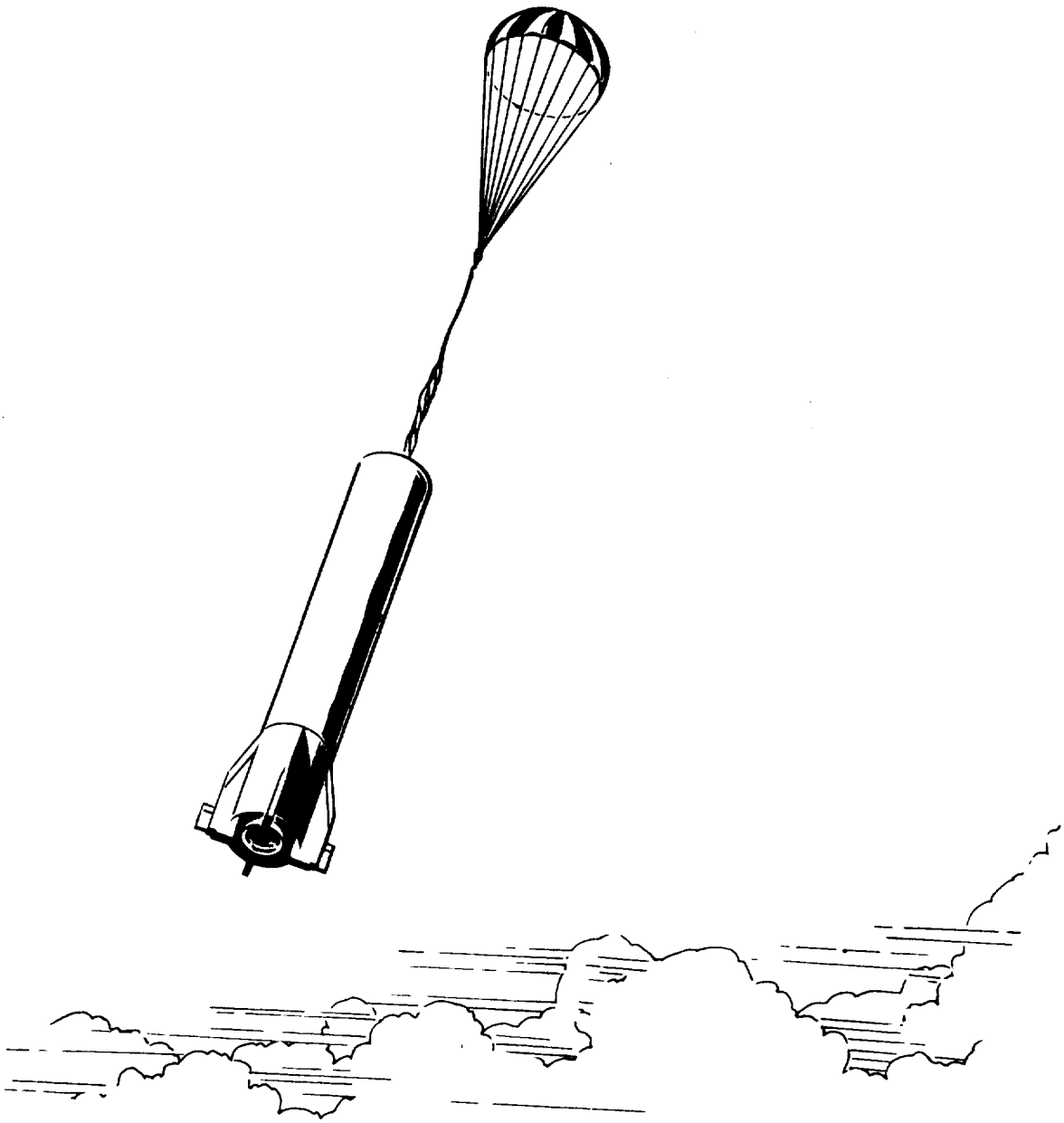


Figure 6-10. Deceleration Parachute Unreefed

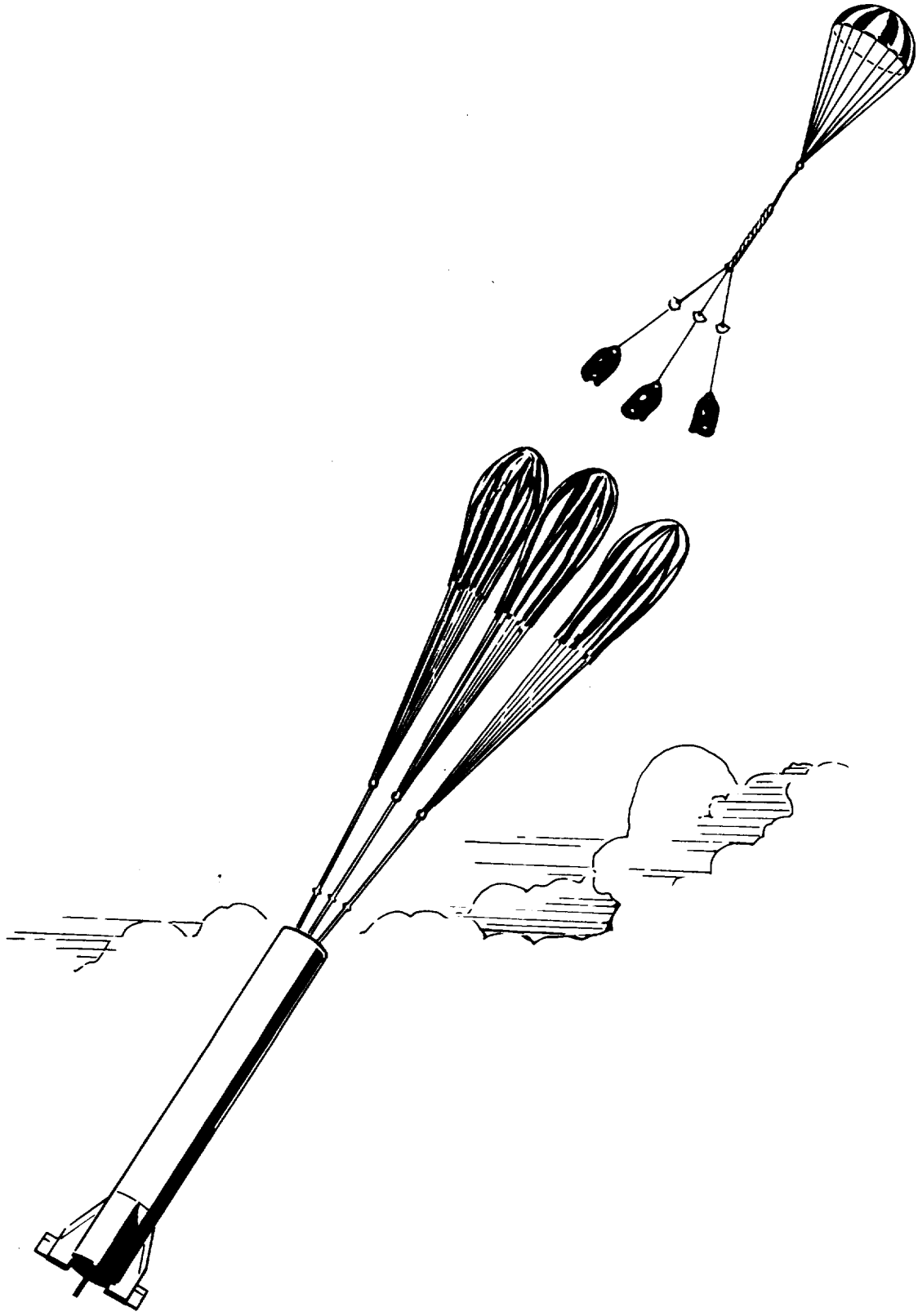


Figure 6-11. Release of Deceleration Parachute and Deployment of Final Recovery Parachutes

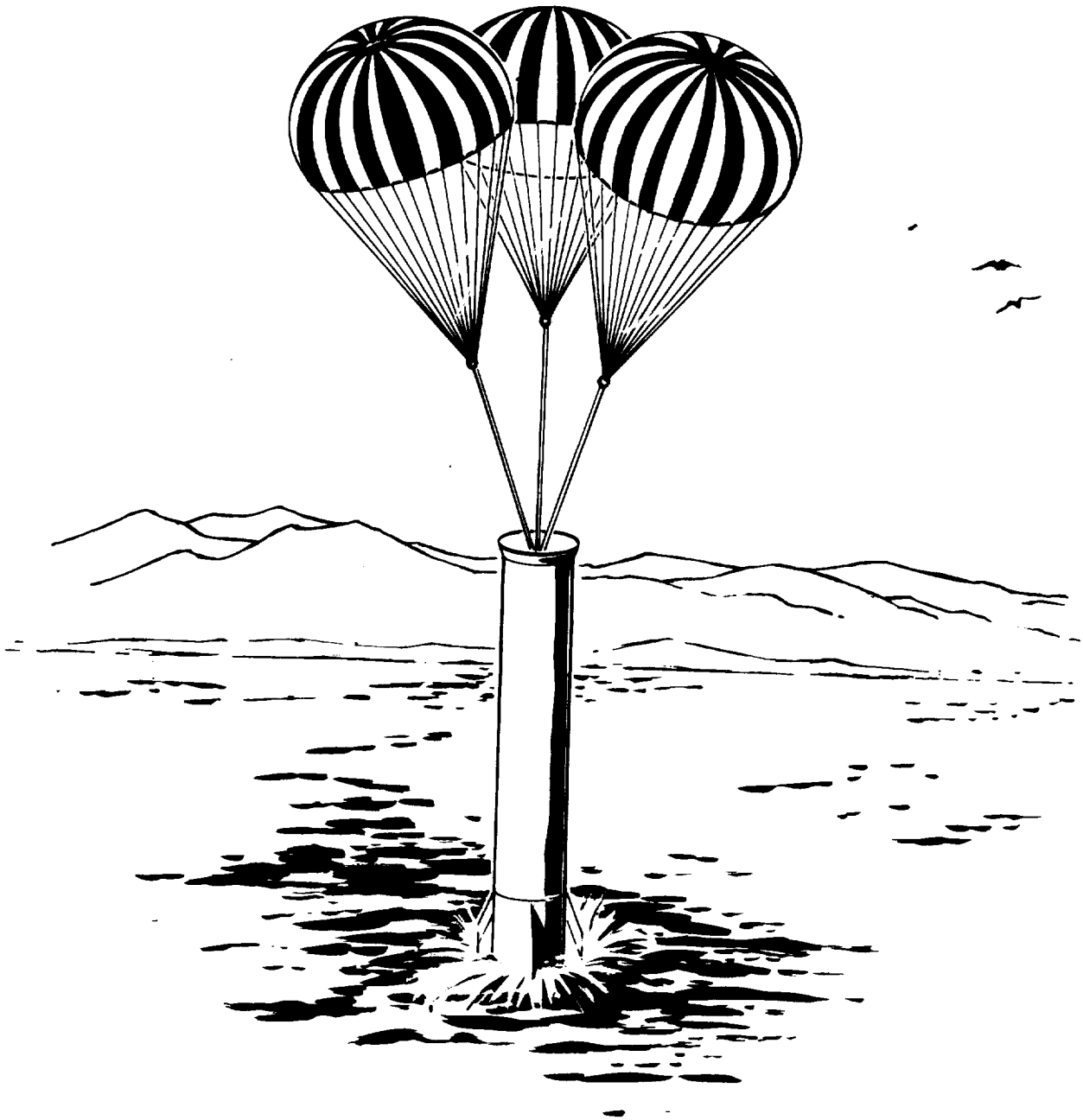


Figure 6-12. Water Impact

6.5.3.2 Sequencing

Regardless of the attitude of fall, the re-entry deceleration peak occurs at a definite time before booster deceleration to subsonic velocity. Thus, with an acceleration sensing device coupled to the timer, it was possible to deploy the first stage parachute into the airstream at high subsonic velocity without regard for booster attitude, altitude, or flight time. The sequencing system as designed, contained, in addition to a g sensing switch, a backup electronic timer (which would start when the REDSTONE program timer ran out) to provide a timed interval sufficient to insure that the booster had decelerated to subsonic speed under all variants of the planned trajectory. At runout of this backup timer, a signal would be given to initiate deployment of the first stage parachute. After the first stage parachute stabilized the booster, the deployment of the three final recovery parachutes was initiated by either of two redundant aneroid switches. The initiation signal from each switch was blocked by the timer for a period of 15 seconds after initiation of the first stage parachute deployment. This delay allowed for the possibility of a late deployment of the first stage parachute in the event that the booster was flying a short-time trajectory at zero angle of attack and had a primary system malfunction. Under these conditions, the booster would have possibly entered the water at greater than the terminal velocity of the final recovery parachutes with the possibility of an unsuccessful recovery.

6.5.3.3 Deployment of Parachutes

The deployment system was designed to use pyrotechnic charges to fire the parachute and its riser with sufficient force to completely entend the riser and initiate parachute deployment within one second. The time limitation selected insured that the parachute would not wrap around a spinning booster. It was estimated that booster rotation would have been less than one-half revolution per second at the time of deployment.

The final recovery parachutes would be deployed by the first stage parachute. Full line and canopy inflation would occur prior to final separation of the first stage parachute.

The first-stage parachute would be deployed in a reefed condition to limit the bending moment on the booster to a value within its structural capability. When sufficient time had passed to orient the booster in a vertical tail-down attitude, the parachute would then be disreefed to allow greater deceleration. When the first stage parachute brought the booster below a 5000-foot altitude, and had been deployed for more than 15 seconds, the rate of descent would have been 300 to 350 feet per second and within the design capability of the final recovery parachutes. At this time the first-stage parachute,

acting as a pilot-chute, would have then extracted and deployed the three final recovery parachutes, which were also reefed to limit the load on the booster. The final recovery parachutes were designed to open in two steps of reefing and to limit the booster's terminal velocity at sea level to approximately 40 feet per second.

6.5.3.4 Parachute Systems

The first-stage parachute was a 17-foot-diameter conical "fist" ribbon type, of high strength design to allow high subsonic velocity deployment. The parachute was attached to a 70 foot long fabric riser which was joined to a 6-foot-long chain riser. The extreme length of riser allowed the parachute to deploy free of the booster regardless of the booster's attitude. The chain riser was necessary due to the sharp lip of the booster-capsule mating joint. The parachute was stowed in a paraflap-type deployment bag which acted as a pilot-chute to insure full stretch of the long parachute riser before releasing and deploying the parachute. To limit its initial opening force to a level which the booster could sustain in any attitude, the first-stage parachute was designed with single stage reefing.

After a time delay sufficient to position the booster in a tail-down vertical attitude, the first stage parachute would have disreefed. It would then open and decelerate the booster to a velocity suitable for final-stage parachute deployment.

The final recovery parachutes were designed as a cluster of three, solid conical canopy, 67-foot diameter parachutes. They attached to individual risers which were permanently attached to the recovery package structure. Since the parachutes were designed for deployment from a stable booster, the riser lengths were of normal length. The final recovery parachutes were arranged for two-stage reefing to permit successful retrieval with one parachute fouled or destroyed, and to limit normal peak loads within the structural strength envelope of the booster.

6.5.3.5 Parachute Containers

The parachute containers and deployment system consisted of mortars for the first stage parachute and its riser, and four fiberglass storage canisters for the final recovery parachutes and their risers.

The first stage parachute was stored in a deployment bag within a pyrotechnic mortar. The top of parachute riser extended from the parachute deployment bag to a deployment bag within the riser mortar. The riser's lower end also extended out of the riser

deployment bag and attached to the chain riser. The chain was attached to an explosive-release mechanism at the center of the recovery unit structure and to a bridle chain of flexible steel cables. The bridle extended to the lids of each of the three final recovery parachutes and single riser canisters. These storage canisters were fabricated of molded fiberglass for thermal protection of the parachutes.

#### 6.5.3.6 Structure

The recovery structure was composed of a conical, six-leg spider with a heavy center hub to which the parachute risers and the first-stage parachute were connected (Figure 6-13). The outer ends of the spokes were attached to the structural attaching ring, and were stabilized by a series of tension members attached to the outer ends of the spokes. The recovery system structure was tested in the MSFC structures test laboratory and proved capable of sustaining and distributing the recovery parachute design loads into the booster structure without damage.

The first-stage parachute disconnect device was attached to the center of the hub of the recovery package structure; the final recovery parachute risers were attached to the center hub. The first-stage deployment mortars occupied two of the six bays between the spokes. The four final recovery parachute system canisters occupied the remaining bays. The electrical system, in two packages, was attached to the mating ring adjacent to one of the access doors of the booster.

#### 6.5.3.7 Heat Protection

Heat protection was necessary to protect the recovery unit from the heat of the separation rocket blast which would have impinged directly upon it. Directly under each nozzle of the separation system was a Dural plate coated with "Refrasil." Over the entire recovery system, under the shields, was a heat protective blanket composed of two layers of heavy fiberglass cloth with an inner layer of glass matting quilted to maintain the blanket's position. A smaller protective blanket of a similar design was installed around the electrical package for additional protection. During first stage parachute separation, the main heat protective blanket would have been removed by the first-stage riser.

#### 6.5.3.8 Instrumentation

Telemetry information to be furnished by the recovery system was limited to temperature, acceleration, and sequencing. The temperature of the outer surface of one of

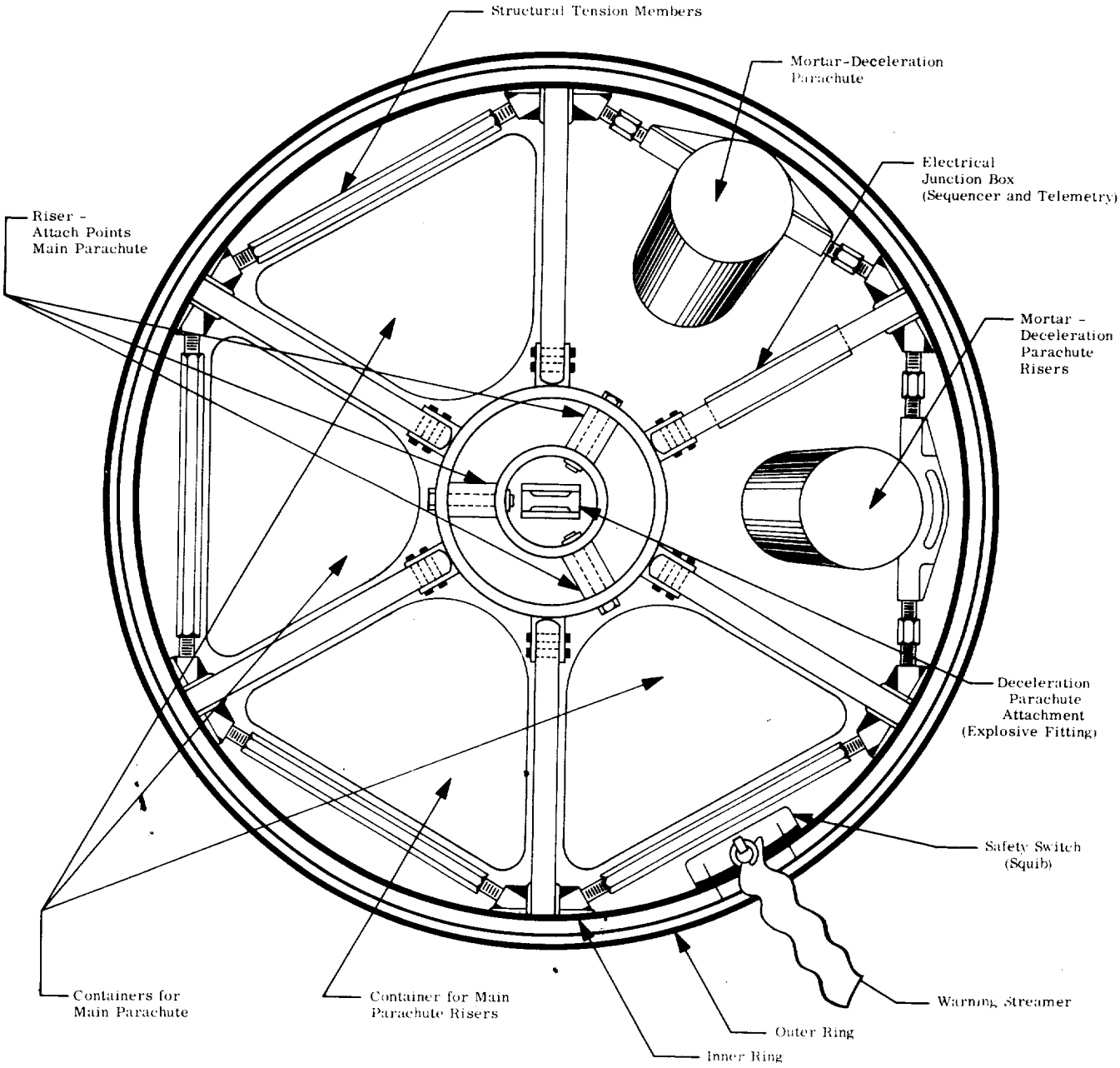



Figure 6-13. Booster Recovery Package

the parachute storage canisters adjacent to the main parachute risers was to be measured. A step-resistance accelerometer network would have telemetered information relative to parachute opening and water entry shock level via means of an output which was to have shown the function of recovery sequencing relative to a time base on the telemetry readout record. The stepping was arranged so that the sequencing readout would have shown whether primary or secondary sequencing operated the system and if sequencing malfunctions occurred.

### 6.5.4 IMPACT AND FLOTATION TESTS

A major problem in the water recovery program for the MERCURY-REDSTONE booster was the determination of possible damage sustained upon water impact, the angle of flotation, and the depth of submersion. The solution to this problem was necessary to determine the best method of safing and retrieval. To measure the extent to which the booster could withstand water impact, tests were conducted at the Madkin Mountain quarry on the Redstone Arsenal.

The impact and flotation tests were conducted with a four-year-old REDSTONE in the quarry's pond which was approximately 25 feet deep. Prior to the test, the booster was altered in weight and configuration so as to simulate MERCURY-REDSTONE booster retrieval conditions. The nose section and all instruments in the aft unit were removed, and a special bulkhead was added for waterproofing and handling purposes.

A carpenter's level and protractor were used to measure angle of flotation of the booster, and a steel tape was used to measure depth of submersion. The depth of penetration of the booster into the water was obtained by using a high-speed camera to photograph a scale printed on the skin of the booster.

During these tests the booster was:

- Floated with fuel and LOX tanks empty.
- Floated with 900 pounds of water in both the fuel and LOX tanks which were pressurized to 10 and 25 psi, respectively. Water was used to simulate probable residual fuel and LOX in tanks after re-entry and impact.
- Dropped from a height of 3 feet to check the instruments and to determine possible damage to the booster.

- Both the LOX and fuel vented with specially designed device, making sure the operator kept his face away from the vent during venting.
- $H_2O_2$ vent and overflow tee capped on one side by a female Roylyn connector. The other side was capped with a male Roylyn connector plus relief valve which provides means for venting the system in the event of internal reactions.
- Dropped from a height of 25 feet to obtain an impact velocity of 40 feet per second, or the estimated impact velocity of the MERCURY-REDSTONE booster upon re-entry when equipped with parachutes.

The maximum vertical acceleration measured during the drop from 25 feet was 13.94 g's and occurred approximately 1/25 second after contact with the water and at a point when the booster had, by calculation, penetrated to a depth of 18 inches and had been decelerated to a velocity of 34.6 feet per second. Since the booster initially traveled at 40 feet per second, one fourth of the kinetic energy had been transferred to the water. The depth of penetration is shown in Figure 6-14. Maximum penetration was 17 feet 4 inches. A trace of the vertical acceleration versus time is shown in Figure 6-15.

Moderate damage was sustained by the fuel tank and the tail unit as a result of the drop tests. The damage was limited to buckling of the skin in the fuel tank section, which, however, remained pressure tight despite the damage. Also, seams in the tail unit burst due to shearing of the rivets.

Calculations prior to the test estimated the angle of flotation of the booster, in a dry condition, to be 4 degrees and the depth of submersion of the aft end to be 81 inches. The actual angle of flotation measured was 2.2 degrees and submersion was 70 inches. With the tanks pressurized and containing residual fuel, the booster floated at 3.2 degrees and was submerged 80 inches at the aft end. The variance of the actual from the pretest calculations was attributed to the buoyancy of the tail unit and rocket engine assembly which were not previously considered.

The final center of gravity of the booster after impact was directly below the longitudinal centerline and was slightly off fin IV toward fin II. This favorable condition meant that the skindivers, with the aid of auxiliary equipment, were able to rotate the booster to any desired position and facilitate safing procedures.

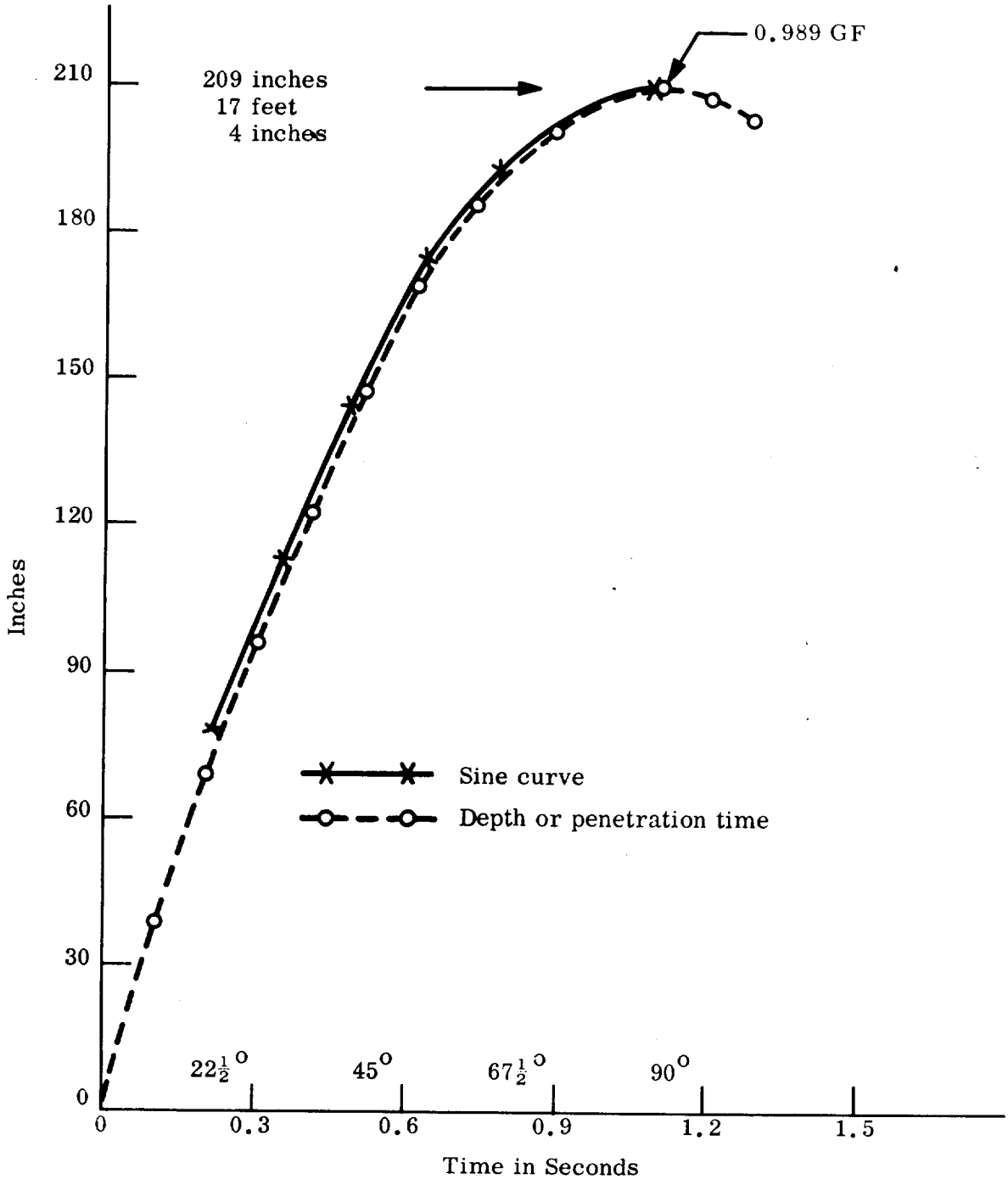



Figure 6-14. Penetration in Inches versus Time in Seconds Showing Close Fit of Sine Curve

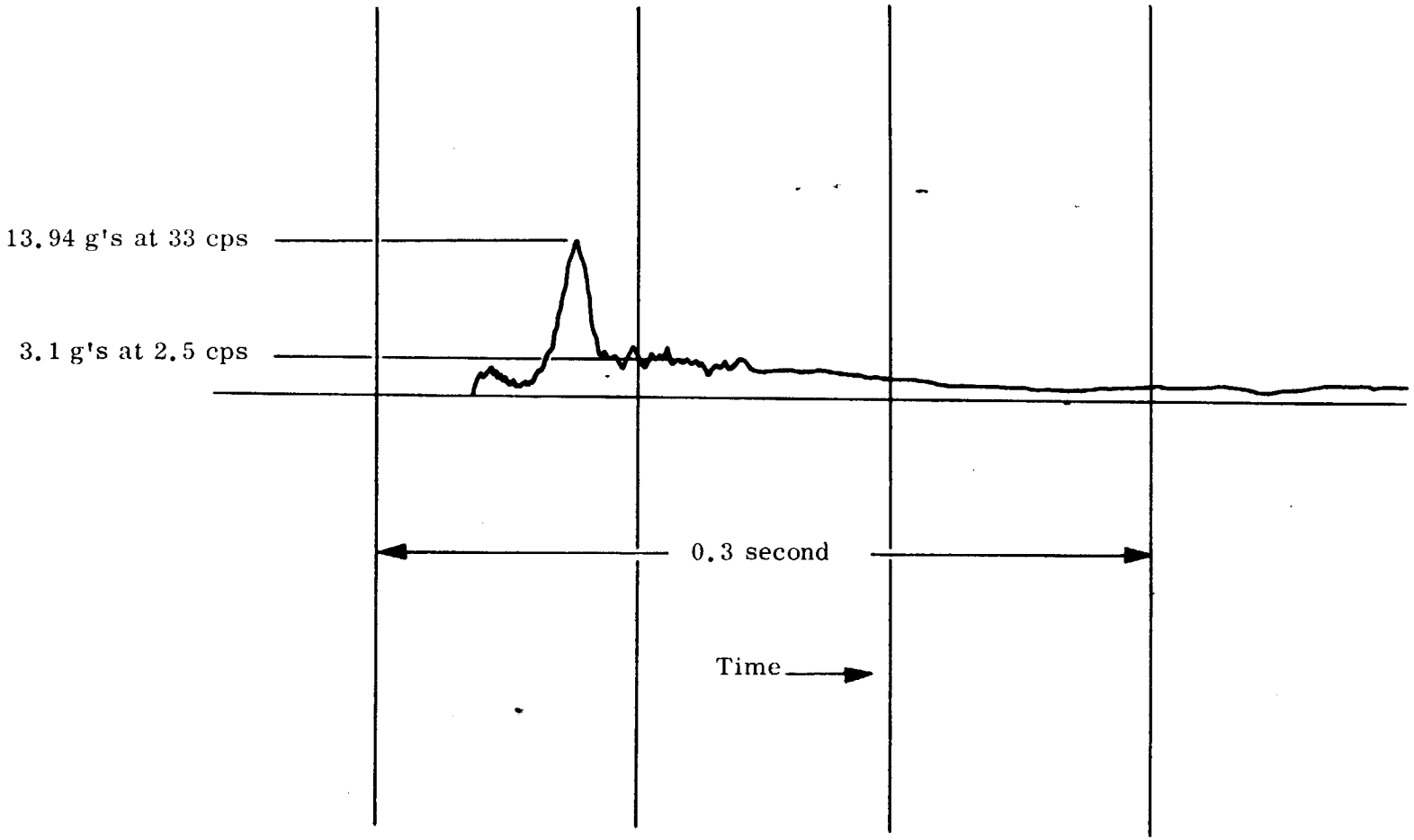



Figure 6-15. Accelerations Measured Vertically on MERCURY-REDSTONE Drop Test

### 6.5.5 SAFING SEQUENCE TESTS

In parallel to the impact and flotation tests, the proper procedures were established for safing the booster prior to floating aboard the recovery vessel.

To simulate water recovery, the booster was first lowered into the water and then was pressurized with $GN_2$. The LOX tanks was pressurized to 30 psig, the fuel tank to 10 psig, and the air pressure spheres to 800 psig. After the pressurizing the booster was permitted to float for approximately 30 minutes. Following the waiting period:

- Airbags were attached to stabilize the booster and to provide accessibility to the destructor unit.
- The destructor unit was checked to assure that it was in its SAFE mode.
- The booster was rotated until the LOX fill and drain valve and the fuel fill and drain valve were accessible.

### 6.5.6 SEA TESTS

An actual recovery from the sea was performed as part of the test program using handling procedures which had been developed and practiced in the quarry test. The results of the tests which were conducted in the Atlantic ocean were:

- The REDSTONE booster could be retrieved by United Stated Naval Vessels with available handling equipment.
- Salt water deterioration to the booster after maximum expected submersion can be kept to a minimum by flushing with a fresh water hose immediately after retrieval.
- Surprisingly little additional rework to the booster is required because of the salt water submersion.

The sea tests were conducted during a two day exercise 50 miles from Norfolk, Virginia. An eight-man underwater demolition team, equipped with hand tools, lines, and replacement fill valves, assisted a landing craft crew in four retrievals of the booster. After safing, the booster was floated onto special cradles attached to the submersible well of a Landing Ship Dock (LSD). The well was then emptied permitting flushing of the booster.

The first recovery operation took place under excellent weather conditions. Ceiling and visibility were unlimited; wind was from the southwest at about 8 knots, with a slight swell from the south.

The primary objective of this first retrieval attempt was to check out the proposed handling procedures. As the first step, the booster, swimmers, and their rubber boat, and the towing crew aboard the Landing Craft Vehicle Personnel (LCVP) were launched. The LSD drained the well and moved away several thousand yards. The swimmers then approached the booster and went through the safing procedures without any difficulty, and also installed the handling connections.

After the safing operation was completed the booster was taken in tow by the LCVP and positioned astern the LSD which was maintaining a constant heading toward the sea. The LSD was ballasted so as to have 8 feet of water in the well at the stern gate sill. The LCVP continued towing until its bow was over the LSD stern gate then reversed, disconnected its tow line, and moved off to the port side and stood by. Swimmers with lines from the LSD attached lines to prescribed connections on the booster, and the booster was positioned over saddles. Once the booster was positioned, deballasting of the well proceeded until booster rested firmly on saddles. After the well was drained, the booster and recovery equipment were checked for damage.

The second operation omitted the safing procedure, but went through with towing the booster out and back into the LSD with the LSD maintaining a heading of 2 to 3 knots into the waves. While the booster was floating at sea, a P2V aircraft was conducting visual training, establishing radar tracking limits, and taking aerial photographs of the operation.

The third operation was very similar to the second. A change on the tiedown location of the nylon retaining slings was made. The slings were positioned so that they went up and over the booster to the opposite wing wall instead of under, around, and over the booster to the wind wall as in the first two operations.

The fourth and final operation was a complete simulated recovery. The booster was set free and all personnel stayed aboard the LSD. The LSD deballasted and steamed off ten miles from booster. At ten miles the booster was held on surface radar while the P2V at a 1500-foot altitude, tracked it a distance of 50 miles.

Once the tracking exercises were over, the LSD started toward the booster. Ballasting of the LSD and preloading of the LCVP were performed while enroute. When the

LSD was approximately 1000 yards from booster, the LCVP was launched and proceeded to the booster. Upon arriving at the booster, the swimmers went through the safing operation; the booster was taken in tow, and brought into the well of LSD and positioned as before.

# SECTION 7

# CHECKOUT AND LAUNCH OPERATIONS

## 7.1 PRELAUNCH PREPARATION

### 7.1.1 GENERAL

Original plans for the MERCURY-REDSTONE vehicle provided for preliminary mating and checkout under laboratory conditions at MSFC prior to delivery to Cape Canaveral Missile Test Annex (CCMTA). This procedure was followed with the first two vehicles, after which it was decided that sufficient experience had been acquired to eliminate test of the mated vehicle at MSFC. It was also originally planned to have a first and second mate at CCMTA for verification of the assembled vehicle with GSE, final preparation of the spacecraft, second mate, and launch, in that order. Experience with the MR-1 vehicle indicated that this procedure was not necessary, and subsequent flights were scheduled for one CCMTA mate only. By the time of the MR-3 flight, launch vehicle delivery was approximately four weeks and capsule delivery approximately fifteen weeks prior to launch for conducting checkouts.

### 7.1.2 PRELAUNCH TESTS

With the exception of launches MR-1 and MR-1A, the spacecraft and the booster arrived at CCMTA separately from St. Louis and MSFC, respectively. The adapter used between the spacecraft and booster, was manufactured by McDonnell Aircraft Company (MAC), shipped to MSFC for a fit test on the particular booster with which it was to be used, then sent to CCMTA where it was fitted to the spacecraft. The launch pad was rehabilitated and the GSE checked out prior to arrival of the launch vehicle. By the time of the MR-4 flight, booster procedures progressed to the point that the launch vehicle was confidently erected on the pad without undergoing hanger checks.

Mechanical mate occurred about 16 calendar days before launch, which provided sufficient time for exhaustive composite vehicle checkout procedures. Following launch vehicle erection, electrical connections were made and continuity checks and bus calibrations performed. During the period between launch vehicle erection and mate, mechanical tests, component calibrations, and measuring component checks were conducted under a schedule predicated on availability of personnel and phasing-in of

booster tests. The diagram in Figure 7-1 shows the building-block approach used in scheduling the MERCURY-REDSTONE launch site checkout. The double asterisks indicate combined spacecraft-launch vehicle tests, and the single asterisks indicate launch vehicle-GSE systems tests.

- Malfunction Sequence Tests

  These tests verify proper operation of cutoff circuits by simulated malfunctions. During the automatic sequence, RF, navigation, and gyro systems are not ordinarily operated.

- Guidance and Control Over-all Test

  This test is conducted to verify proper operation of all vehicle systems. All systems of both spacecraft and launch vehicle are operated. Umbilical release and retraction is simulated, and ordnance systems monitoring is performed.

- Guidance and Control Plug Drop Over-all Test

  This test verifies the compatibility and proper operations of all vehicle systems while simulating the firing as closely as possible. All systems of all stages are operated, the umbilicals released and one-shot relays and explosive switches are fired. Range support is required for this test.

- Simulated Flight Test

  This test is conducted to verify compatibility and proper operations of all vehicle systems. Umbilical release is simulated, all systems of spacecraft, vehicle, and range are operated, and ordnance systems are monitored. Range support is required for this test.

- Booster Integrated Test

  Booster integrated test includes network, mechanical, and measuring over-all tests. Command receivers are normally operated but all other RF systems, gyro systems, and navigational systems are not operated. These tests are normally conducted in preparation for the final combined systems over-all test such as the guidance and control over-all test, the plug drop over-all test, and the simulated flight test. Individual major tests are indicated in separate blocks and are adequately defined by their titles.

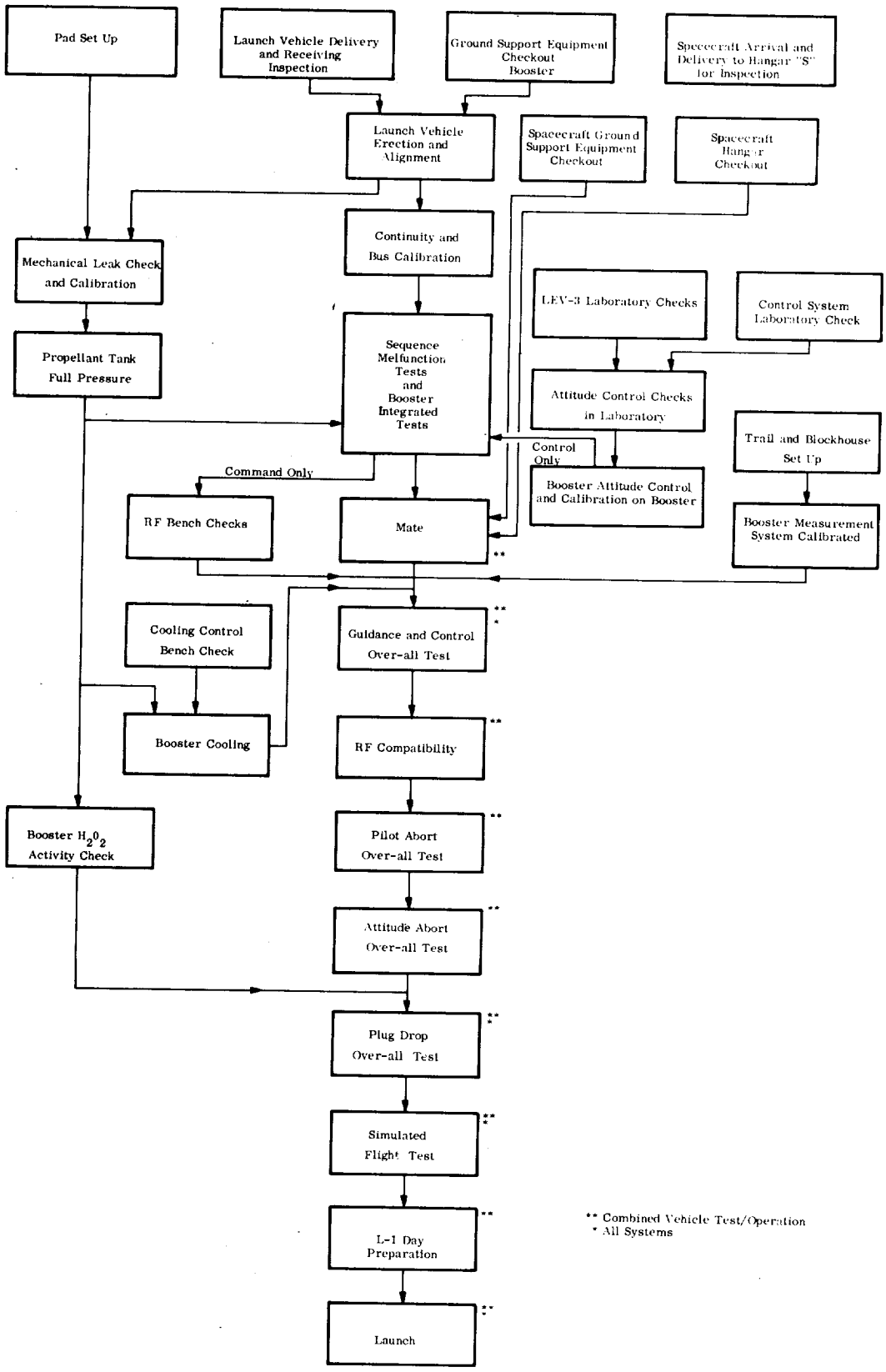



Figure 7-1. Launch Site Checkout Scheduling

Mechanical prelaunch checkout of the booster vehicle was carefully conducted under the direct supervision of the responsible design engineer. Approximately 18 mechanical tests were conducted. Each test entailed preparatory steps and specific operating procedures. A list of such tests by descriptive titles follows:

Functional test - Fuel tank pressure switch.
Functional test - Engine control pressure switch.
Functional test - Combustion chamber pressure switches 1 and 2.
Leakage test - High pressure system.
Leakage test - Engine and ground control pressure systems.
Leakage test - Hydrogen peroxide system.
Leakage test - Steam exhaust system and turbopump functional test components test.
Leakage test - Igniter fuel system.
Pressure test - Propellant tanks simulated full.
Leakage test - LOX system.
Leakage test - Fuel system.
Leakage test - Combustion chamber.
Pressure test - LOX and fuel tanks full.
Leakage test - Combustion chamber pressure switches sensing lines.
Functional test - LOX replenishing system.
Leakage test - Instrument compartment.
Activity test - Rocket engine hydrogen peroxide system.

### 7.1.3 SCHEDULE OF PRELAUNCH ACTIVITIES

Throughout the MERCURY-REDSTONE Program, procedures were adjusted to provide for a more effective operation, based on experience and familiarity with the launch vehicle. The final schedule of launch vehicle checkout procedures for the MR-4 launch encompassed 21 workdays, compared with 46 workdays on MR-1. The checkout history of MERCURY-REDSTONE vehicle MR-4 was utilized in establishing the chronological sequence of operations listed below. The operations are listed by calendar days, L indicates launch day and the number indicates days prior to launch day.

- L-25 Booster arrival and erection on launcher. Cable masts erected, vertical alignment, and positioned to flight azimuth.
- L-24 Apply electrical power and operational check of command receivers. Begin measuring calibration and mechanical preparations.

- L-23 Mechanical systems test, including component and leak tests. Laboratory calibration of abort rate switches. Measuring calibration continued.
- L-22 Not a work day.
- L-21 Continue mechanical checks and measuring calibration. Check telemetry, AZUSA, and DOVAP.
- L-20 Full pressurization test. Program device checks and verification.
- L-19 Booster over-all test number 1 as follows:
  a. Ready-to-fire failure cutoff.
  b. Ignition failure.
  c. Destruct command receiver.
  d. Cutoff arming to capsule.
  e. Install booster recovery package ballast.
- L-18 Functional cooling system check, gyro control tests.
- L-17 Complete cooling test.
- L-16 Mechanical mate of spacecraft to booster.
- L-15 Not a work day.
- L-14 Electrical mate of spacecraft and booster, over-all test number 2, and off-the-pad abort test.
- L-13 Over-all test number 1, normal flight sequence.
- L-12 Partial RF compatibility test, astronaut insertion procedures, and booster peroxide system activity test.
- L-11 Complete RF compatibility test, and conduct egress tests.
- L-10 Not a work day.
- L-9 Not a work day.
- L-8 Over-all tests as follows:
  a. Over-all test number 3, emergency override test.
  b. Over-all test number 4, pilot abort test.
  c. Over-all test number 5, attitude abort test.
- L-7 Evaluation of over-all tests 3, 4, and 5. Verification of any questionable areas.
- L-6 Plug drop over-all test.
- L-5 Preparation for simulated flight test, and booster ordnance item fit checks.
- L-4 Simulated flight test.
- L-3 Booster instrument compartment pressurization test, and booster flight safety, and mission review meeting.

- L-2 Not a work day.
- L-1 First portion of divided countdown.
- L-0 Weather briefing, second portion of countdown, and launch.

## 7.2 LAUNCH ORGANIZATION AND COUNTDOWN

### 7.2.1 RESPONSIBILITIES

#### 7.2.1.1 General

Figure 7-2 shows the MERCURY-REDSTONE launch organization as it evolved for the flight of MR-4. The broken lines enclose the blockhouse functions, the solid connecting lines show the lines of action, and the dashed connecting lines are lines of coordination.

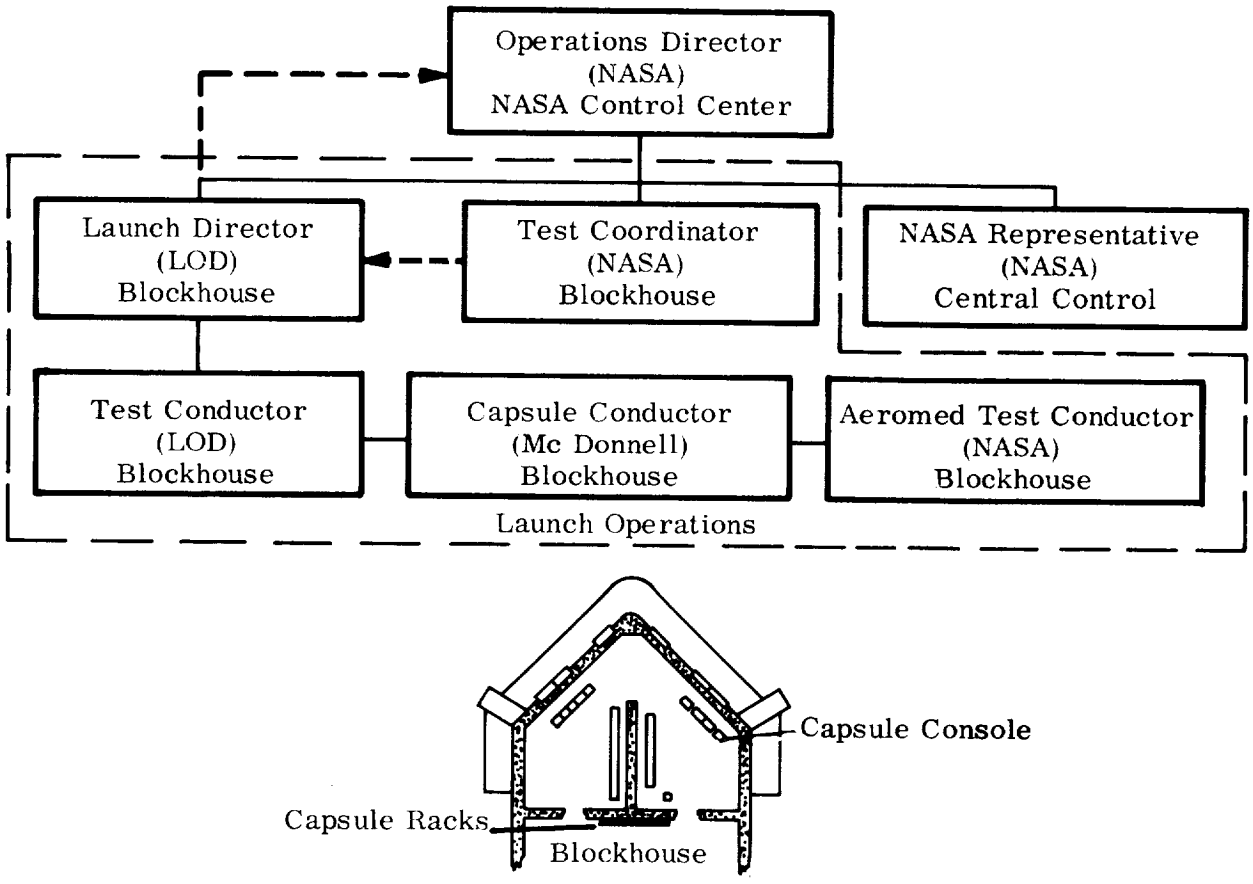



Figure 7-2. MERCURY-REDSTONE Launch Organization

### 7.2.1.2 Operations Director

Over-all mission control was exercised by the operations director. In carrying out this responsibility, he was supported by the launch director and flight controller. A delineation of responsibility and support functions are presented in a document entitled Over-all Plan, Department of Defense Support for Project MERCURY Operations prepared by the Department of Defense (DOD), representative for Project MERCURY, dated 15 January 1960. At the MERCURY Control Center (MCC), the operations director received information from the launch director, tracking and data acquisition network, recovery organization, launch coordinator, and the flight controller. Through a representative in the MCC, the blockhouse kept the operations director advised of booster progress and principal events throughout powered flight.

### 7.2.1.3 Launch Director

The launch director was responsible for the technical readiness of the launch vehicle system, the launch complex, AMR support, and for accomplishment of launch objectives. Technical problems concerning the capsule and astronaut relating to the mission were referred to the operations director for decision. The launch director had responsibility for the countdown, abort command to liftoff plus eight seconds, emergency egress, and he was responsible for monitoring the powered flight of the launch vehicle until spacecraft separation. The launch director had technical supervision of the launch operation. The test conductor reported to the launch director, and in turn was supported by a capsule test conductor. A single action point of contact with AMR operations was maintained through the test conductor to assure that all information emanating from the blockhouse was complete and properly coordinated to eliminate the possibility of contradictory or overlooked support requirements.

### 7.2.1.4 Test Conductor

The test conductor also acted as the launch vehicle test conductor and was supported directly by the launch operations range coordinator, the blockhouse and complex launch vehicle systems engineers, and contractor personnel involved in the launch operation. The capsule test conductor, in turn, was supported by a capsule systems engineer, a capsule communicator (one of the astronauts), and aeromedical personnel. The capsule systems engineer coordinated the pad and blockhouse activities of McDonnell personnel in support of the launch operation.

#### 7.2.1.5 Range Coordinator

The launch operations range coordinator was in continuous communication with the superintendent of range operations to assure that the AMR countdown was in phase with, and properly supporting, the entire launch function.

### 7.2.2 MISSION RULES AND LOD SCRUB PRIORITY LIST

Two additional important documents that were used during the MERCURY-REDSTONE launch countdowns were the mission rules and LOD scrub priority list shown in Table 7-1. The LOD scrub priority list established priorities for booster onboard equipment and instrumentation. This priority list was used as a quick reference guide to a hold or scrub in case of foreseeable booster or GSE malfunctions. It also listed weather criteria and range safety requirement for the launch. The mission rules provided similarly appropriate priorities for the spacecraft systems and the MCC.

Table 7-1

MERCURY-REDSTONE Mission Rules and Scrub Priority List

| Action | Commands | Remarks |
|---|---|---|
| Abort | Abort of the mission will only be commanded:<br>a. From the blockhouse: On the basis of impending booster catastrophic failure either on the pad or during powered flight.<br>b. By the RSO, for range safety reasons during powered flight.<br><br>Capsule or booster malfunctions will not be cause for abort command from control center. | Booster abort system installed open loop on MR-1, 1A, and BD. (Abort system is open loop on flights MR-1, 1A, and BD only.)<br><br>Blockhouse monitors booster by telemetry.<br><br>Blockhouse abort command is to capsule command receivers only.<br><br>RSO Commands:<br>a. Booster engine shutdown.<br>b. Booster destruct: (3-second time delay built into booster between shutdown and destruct arming). |

Table 7-1

MERCURY-REDSTONE Mission Rules and Scrub Priority List (Cont.)

| Action | Commands | Remarks |
|---|---|---|
| Retrofire | Retrofire will be commanded by control center. | Onboard timer will be considered as backup. |
| | Blockhouse | |
| Booster telemetry displays - for abort control | Mandatory. | |
| Command | Mandatory. | |
| | Recovery Forces | |
| Capability | Recovery is mandatory. | |
| | Weather Minima | |
| Launch area | Surface winds - 18K maximum,<br>Upper winds - 120K maximum at any altitude.<br>Sea state - 3 or calmer.<br>Visibility - 5 miles.<br>Cloud coverage - no cloud coverage that will preclude camera coverage of booster operation from liftoff through separation. | Capsule impacts predicted to occur in an unsatisfactory landing area may be the basis for a no-go decision. |
| | Range Instrumentation Support | |
| | | Countdown action if instrumentation fails during count. |
| Flight safety | AZUSA Mark I | Hold |
| | Beat-Beat Mark II | Proceed |
| | Telemetry ELSEE | Proceed |
| | Mod IV radar | Proceed |
| | Mod II radar (S-band, SCR-584) | Proceed |
| | FPS-16 (C-band) Station 1-16 (Cape) | Hold |
| | FPS-16 (XN-2, C-band) Station 3-16 (GBI) | Proceed |
| | FPS-16 (XN-1, C-band) PAFB-Stanley | Proceed |
| | FPS-8 Surveillance radar | Proceed |
| | FPS-20 Surveillance radar sky screen, vertical wire | Proceed |
| | Command system | Hold |

Table 7-1

MERCURY-REDSTONE Mission Rules and Scrub Priority List (Cont.)

| Action | Commands | Remarks |
|---|---|---|
| Electronic instrumentation | MPS-25 (Carter Cay C-band) | Proceed |
| | FPS-16 (XN-1, PAFB) | Proceed |
| | DOVAP (uprange) transmitter | Proceed |
| | DOVAP-blockhouse, receiver | Proceed |
| | Tel-2 (TCM-18) telemetry antenna | Hold |
| | Telemetry ship (1 required) | Hold |
| | Telemetry aircraft | |
| Optical tracking instrumentation (see Weather) | Documentation and sequential | Proceed |
| | Metric cameras | Proceed |
| | Cine theodolitic (Askania) | Proceed |
| | CZR cameras | Proceed |
| | ROTI (Melbourne and Vero Beach) | Proceed if one operates |
| | ROTI Melbourne Beach | Proceed if one operates |
| | ROTI Vero Beach | Hold if both are out |
| | IGOR PAFB | Proceed |
| | IGOR False Cape | Hold |
| | IGOR, Williams Point | Proceed |
| Primary and Secondary Recovery Area: | Ceiling - 2000 feet<br>Visibility - 5 miles<br>Surface winds - 18K | |

## 7.2.3 LAUNCH COUNTDOWN

### 7.2.3.1 Countdown Procedures

To prevent personnel fatigue, the 10-hour MERCURY-REDSTONE countdown was performed in two parts. The first of these parts was performed on the day preceding launch day and covered the operations normally performed from T-640 to T-390 minutes of the countdown. The second part began at approximately 2300 hours on the day preceding launch (including built-in holds) and covered the operations normally performed from T-390 minutes of the countdown until vehicle liftoff. This system of operation afforded the launch crew several hours of rest at approximately midway in the count. As a result, the crew was less fatigued and more alert during the critical launch time when proper response is most essential. On those occasions when a launch was scrubbed and rescheduled after the first section of the count had been completed, only the second portion of the count was performed if the launch was rescheduled within a short period of time.

To assure that all functions during a countdown were properly integrated, the responsibility for such integration was assigned to the over-all test conductor. Scheduling of prelaunch tests was similarly accomplished. The launch vehicle test conductor prepared the master operational schedule following coordination with STG, AMR, LOD, and other participating organizations. Countdown procedures on the capsule were prepared in detail by McDonnell Aircraft Company and were closely coordinated with the over-all launch countdown to assure the timely phasing-in of capsule operations. The master operational schedule was considered the master document, and the AMR and procedure were geared accordingly.

Detailed countdown procedures were written for use in checking out the many systems and subsystems of the capsule and booster. The countdown document included each key procedure of major importance and each was identified by the title of the responsible individual in the countdown. These procedures appeared at the proper time and in proper sequence in the count. As each test or procedure was completed, the cognizant engineer reported the fact to the test conductor who then checked it off the list.

Due to unforeseen developments, some last minute requirements are normally written into all affected launch procedure documents. Experience gained in earlier operations indicated that rapidly changing weather conditions could cause a delay such that it became necessary to scrub the launch. A scrub prior to LOX loading required only rescheduling the beginning of the next countdown. A scrub after LOX loading required emptying the LOX and purging and drying the launch vehicle, the process requiring approximately 12 hours. The precount and final count could then begin subject to the target launch crew rest requirements. It was decided, therefore, that LOX loading would be delayed to occur as close to vehicle liftoff as feasible. As a result, the LOX loading time was shifted from T-305 minutes to T-180 minutes in the countdown. This change was made between the MR-3 and MR-4 launches. A bar chart of the schedule of countdown procedures and launch vehicle status for the MR-4 launch is presented in Figure 7-3.

#### 7.2.3.2 Detailed Countdown Schedule (MR-4)

The following pages present the complete countdown schedule for the MR-4 launch. An explanation of the code utilized to identify responsibilities (e.g., PAD-M) is given at the conclusion of paragraph 7.2.3.2. Part I details from T-640 down to T-390 minutes, Part II, details T-390 minutes through T-0 liftoff.

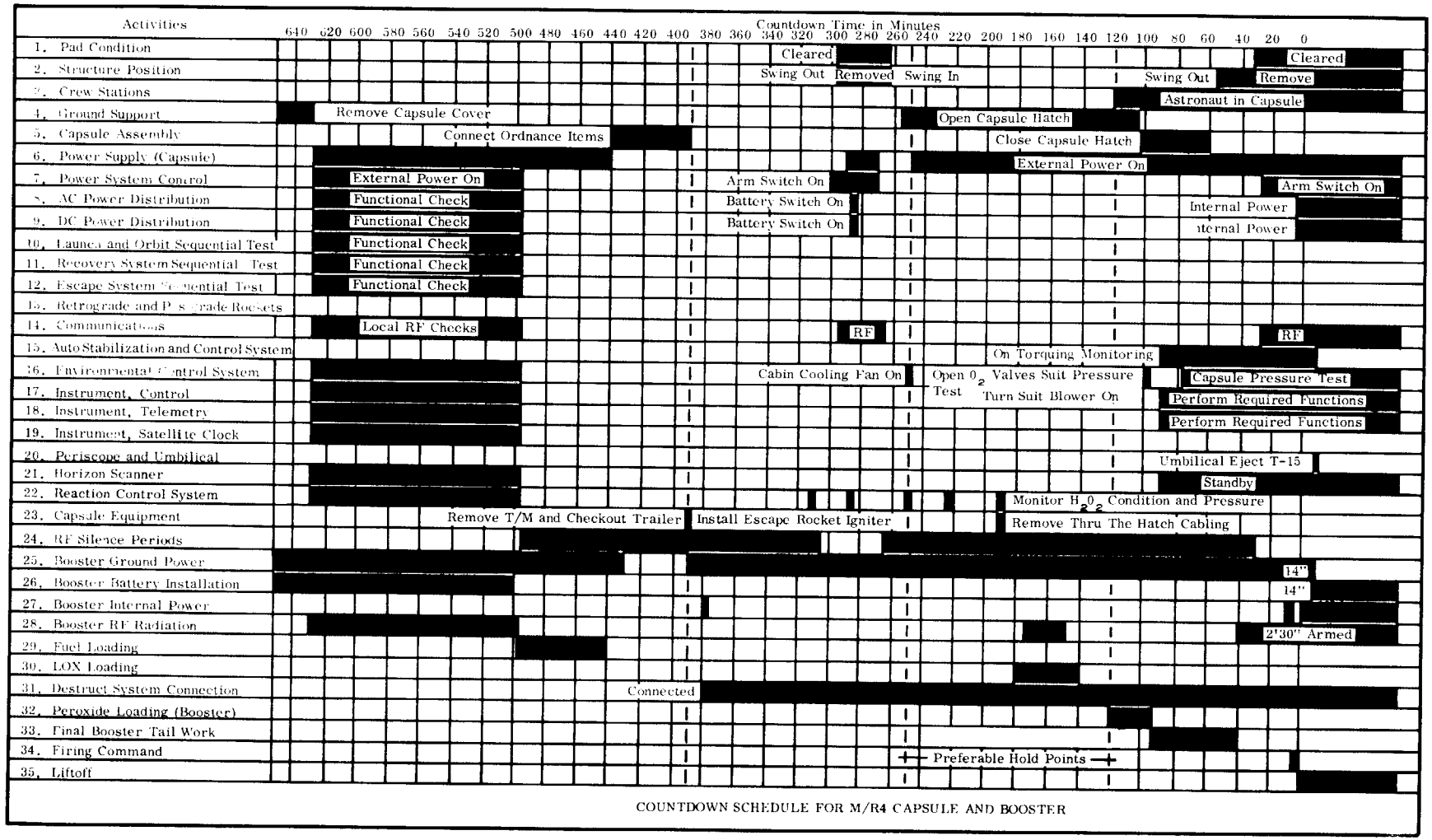



Figure 7-3. Bar Chart on Vehicle Countdown Status

| | | | |
|---|---|---|---|
| T-640 | 1. | RANGE | Verify complex is on critical power. |
| | 2. | PAD-M | Open instrument compartment and aft section doors. |
| | 3. | BH-CAP and PAD-CAP | Capsule personnel man appointed stations. |
| | 4. | PAD-E | Deliver, install, and safety wire booster batteries (except control battery). |
| | 5. | M | Block booster abort On. |
| | 6. | BH | After roger from PAD-E apply booster power (prelaunch). |
| | 7. | GEN | Adjust generator voltages to flight battery voltage data. |
| | 8. | PAD-M | Remove the following covers and sealing tapes:<br>a. LOX tank vent valve.<br>b. $H_2O_2$ tank vent valve and overflow assembly. (Replace after components test.)<br>c. LOX pump seal drain.<br>d. Steam seal drain. (Replace after components test.)<br>e. Alcohol pump seal drain.<br>f. Alcohol vent valve.<br>g. LOX replenish vent cap.<br>h. Check annin valve.<br>i. Leave shelter ring On with sides Off. |
| | 9. | RANGE | RF clearance for DOVAP frequencies. |
| | 10. | PAD-E and G | Check LEV-3 pots (perform work during RF silence period). |
| | 11. | PAD-CAP | Remove capsule covers and open for work. |
| | 12. | I | Ground inverter On. |
| | 13. | I | Booster inverter On. |
| | 14. | M | Booster measuring voltage On. |
| | 15. | MEAS | Warmup blockhouse measuring and recording equipment. |
| | 16. | MEAS | Calibrate all recorders and make final checks. |

| | | | |
|---|---|---|---|
| T-640 (Cont.) | 17. | AB and RF | Warmup telemeter ground stations. |
| | 18. | PAD-M | Remove pins from capsule retaining ring retaining devices. |
| | 19. | PAD-E | Connect over-all test cable for control battery substitute. |
| T-635 | 1. | BH-CAP and PAD-CAP | Communication check. (Hardwire only.) |
| | 2. | BH-CAP and PAD-CAP | Prepare all capsule subsystems for test. |
| | 3. | RF | Proceed with DOVAP tuneup checks. (Vehicle transponder may be used anytime prior to T-410.) |
| T-625 | 1. | PAD-M | Fill booster spheres to approximately 1500 psi. |
| | 2. | PAD-M | Set up control pressures required for power plant components test (including cooling system and topping system). |
| | 3. | PAD-M&P | Perform components test according to procedure. |
| | 4. | PS | Check liftoff and camera start circuits as required by AMR. |
| | 5. | SEQ | Check blockhouse sequence recorders. |
| | 6. | PAD-E | Check azimuth alignment of LEV-3 (to be given a final launch check at T-130). |
| | 7. | RANGE | RF clearance for all capsule RF equipment: Telemeter, HF Recovery, S-band beacon, UHF Recovery, C-band beacon, Command |
| | 8. | PAD-CAP and BH-CAP | Apply capsule power. |
| | 9. | PAD-CAP and BH-CAP | Begin systems test. |
| | 10. | RANGE | RF clearance for all booster RF equipment: Telemeter 230.4 Mc (U); AZUSA 5000 Mc (U) |
| | 11. | RF and AB | Tune booster telemetry for flight. |
| T-620 | 1. | PAD-MEAS and PAD-M | Move measuring trailer to adjacent Complex 26 and stow for launch. |

| | | | |
|---|---|---|---|
| T-620 (Cont.) | 2. | PAD-M | Ready water lead filling equipment after components test. |
| | 3. | P and PAD-M | Load water. |
| | 4. | PAD-M | Drain 680 cc water. |
| | 5. | PAD-M | Remove tail weather shelter. |
| T-610 | 1. | PAD-M | Install fuel overflow line after verifying fuel vent is open. |
| T-605 | 1. | C | Control voltage On. |
| | 2. | G | Bring LEV-3 gyros On for warmup prior to flight integrator setting and attitude abort checks. |
| | 3. | RANGE | Standby for S- and C-band radar beacon checks. S- and C-band radars away from PAD. |
| T-600 | 1. | BH-CAP | C- and S-band radar beacon On. |
| | 2. | RANGE | Readout C- and S-band radar beacons for qualified Go. |
| | 3. | GEN | Check voltage clear after battery installation. |
| T-580 | 1. | TC | Reset TC panel. |
| | 2. | M | Step dummy S&A block to arm and safe. |
| T-540 | 1. | PAD-M | Verify control pressure removed from capsule mast release valve. Do not apply pressure until cleared with test supervisor. Leave hand vent valve open. |
| | 2. | P | Verify Cap Mast 750 (light Off). |
| T-530 | 1. | RANGE | Standby for initial command control checks. |
| | 2. | PAD-E | Double check that Dummy destruct block is connected and verify. |
| | 3. | RANGE | Prepare AZUSA ground station for range check. |
| | 4. | PAD-CAP | Verify shorting plug in escape tower. |

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|---|---|---|---|
| T-530 (Cont.) | 5. | PAD-E | Remove fuses in booster tail plug and booster boom plug for hardwire abort (Fuse box No. 5, Red fuses 24 and 25; Fuse box No. 2, Green fuses 33 and 34). |
| | 6. | PAD-E | Remove TBI fuses 1, 2, and 3. |
| | 7. | PAD-E | Install Jumper E5 - E6. |
| T-520 | 1. | PAD-M | Move fuel (alcohol) trailer into fueling position. |
| | 2. | PAD-M | Turn On yellow warming light. |
| | 3. | M | AZUSA blower On. |
| | 4. | M | AZUSA On. |
| | 5. | RANGE | Check booster AZUSA transponder with range station. |
| | 6. | NOTE | Refer to special sequence test procedures. |
| T-515 | 1. | RANGE | Roger AZUSA transponder check. |
| | 2. | M | AZUSA Off. |
| | 3. | M | AZUSA blower Off. |
| | 4. | PAD-M | Remove caps from instrument compartment pressurizing switch and pressurizing valve. |
| T-500 | 1. | ALL BOOSTER STATIONS | Standby for booster power transfer test sequence. |
| | 2. | PAD-PAA | Top off 5000 psi $GN_2$ batteries if required. |
| | 3. | PAD-E | Verify all flight batteries are installed and secured (except control battery). |
| | 4. | PAD-M | Make final vehicle plumbing checks prior to fuel loading. |
| T-497 | 1. | RF | Verify DOVAP reference transmitter On. |
| | 2. | RF | Verify DOVAP test transmitter Off. |
| T-495 | 1. | G | Verify Gyro system ready. |
| | 2. | M | Command receiver No. 1 On. |
| | 3. | M | Command receiver No. 2 On. |
| | 4. | M | Telemeter On. |
| | 5. | M | Calibrator On. |
| | 6. | C | Control computer On. |

| | | | |
|---|---|---|---|
| T-495 (Cont.) | 7. | C | Program device On. |
| | 8. | P | Verify autopilot ok light On. |
| | 9. | TC | Announce warning of instrument compartment pressurizing valve operation during power transfer. |
| | 10. | PAD-M | Monitor instrument compartment pressurizing. |
| | 11. | GEN | Over-all test power On. |
| | 12. | SEQ | Sequence and E&I recorders to minute speed. |
| | 13. | SEQ | Time pulse On. |
| | 14. | M | DOVAP On. |
| | 15. | M | AZUSA blower On. |
| | 16. | M | AZUSA On. |
| | 17. | RF | Telemeter recording On (LOD only). |
| | 18. | C | Rudder drive On. |
| | 19. | C | Verify servo voltage ok (light On). |
| | 20. | P | Verify voltages ok (light On). |
| | 21. | AXN | Power transfer test On and Off (momentarily). |
| | 22. | SEQ | Record all battery bus voltages. |
| | 23. | G | Simultaneous command On and Off. |
| | 24. | L | Network roger of satisfactory power transfer. |
| | 25. | AXN | Emergency booster power Off (verify). |
| | 26. | C | Rudder drive Off. |
| | 27. | RF | Telemeter recording Off (LOD only). |
| | 28. | M | Secure all RF systems. |
| | 29. | SEQ | Secure all recorders. |
| | 30. | C | Control computer Off. |
| | 31. | PD | Check program device flight tape. |
| | 32. | G | Torque each LEV-3 gyro ± until abort is indicated by TC. |
| | 33. | G and PAD-E | Calibrate integrator cutoff signal. |
| T-490 | 1 | P | Weight reading prior to fuel loading (clear vehicle when announcement is made and verify to TC). |
| | 2. | MEAS | Monitor fuel tank pressure. |

| | | | |
|---|---|---|---|
| T-490 (Cont.) | 3. | P and PAD-M | Start fuel loading. |
| | 4. | PAD-M | Fill igniter tank. |
| | 5. | PAD-M | Check for fuel leakage in tail. |
| | 6. | PAD-M | Torque main LOX bolts. |
| | 7. | CTC | Verify spike and ballast on fourth platform. |
| | 8. | PAD-M | Watch fuel vent for overflow. |
| T-450 | 1. | CTC | Roger completion of capsule system tests. |
| | 2. | CTC | Roger removal of test cables. |
| | 3. | PAD-CAP | Remove all capsule test cables (except shorting plug). |
| | 4. | G | Secure LEV-3 gyros. |
| | 5. | C | Control voltage Off. |
| | 6. | CTC and PS | Arm squib bus and begin no voltage checks. |
| T-440 | 1. | P and PAD-M | Finish fuel loading. |
| | 2. | PAD-M | Dip stick fuel to determine ullage. |
| | 3. | P | Weight reading after fuel loading (clear vehicle when announcement is made and verify to TC). |
| | 4. | CTC and PS | Disarm squib bus after no voltage checks. |
| | 5. | BH | Establish vehicle RF silence. |
| | 6. | M | RF Silence Switch On. |
| | 7. | ANNOUNCEMENT | All personnel not having specific vehicle preparation activities clear service structure for capsule ordnance connection. |
| | 8. | CTC | Remove capsule power. |
| | 9. | PAD-CAP | Remove shorting plug and connect all ordnance except escape rocket. |
| | 10. | PAD-M | Remove fuel trailer. |
| T-420 | 1. | PAD-M | Adjust TRMV based on trailer alcohol temperature. |
| | 2. | PAD-M | Safety wire TRMV. |
| | 3. | BH | Secure booster power. |
| | 4. | PAD-M | Engine control regulated to zero psig. |

Part I - Launch Countdown (Cont.)

| | | | |
|---|---|---|---|
| T-400 | 1. | PAD-M | Install tail weather shelter - pending weather. |
| | 2. | PAD-M | Resume LOX pump bearing purge. |
| | 3. | PAD-M | Install following covers and sealing tapes:<br>a. LOX tank vent valve.<br>b. $H_2O_2$ tank vent and overflow assembly.<br>c. Steam seal drain. |
| | 4. | PAD-M | Install instrument compartment door O-rings. |
| | 5. | PAD-M | Final vacuuming. |
| T-390 | 1. | END | END operations on first part of split count and secure all systems for standby period. The count will be resumed at T-390 minutes at the predesignated time. |

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| | |
|---|---|
| CAPSULE PERSONNEL | Prepare capsule and ground system for peroxide loading. |
| PS and PAD-CAP | Load capsule peroxide and monitor system. |

Part II - Launch Countdown

Preparatory steps for picking up the second section of the count:

| | | |
|---|---|---|
| 1. | M | Verify RF silence switch On. |
| 2. | PAD-CAP | Install, but do not connect, escape rocket igniter (complete 60 minutes before pickup) - area must be cleared. |
| 3. | C | Close flight sequence reset switch. |
| 4. | BH and PAD-E | Apply booster power. |
| 5. | PAD-M | Remove following covers and sealing tapes:<br>a. LOX tank vent valve.<br>b. $H_2O_2$ tank vent and overflow assembly.<br>c. Steam seal drain.<br>d. Cap Off instrument compartment pressurizing and sensing lines. |
| 6. | RANGE | Weather forecast. |
| 7. | BH | Verify RF silence. |
| 8. | PAD-M | Install destruct block and connect primacord to destruct block (do not connect electrically). |

| | | | |
|---|---|---|---|
| | 9. | PAD-M | Connect cable mast No. 1 (booster), eject control line and cable mast No. 2 (capsule), eject control line. |
| | 10. | PAD-CAP | Prepare capsule checkout trailer for moving. |
| | 11. | PAD-CAP | Move capsule checkout trailer to launch. |
| | 12. | RANGE | Standby to resume count. |
| | 13. | PAD-E | Make resistance check of TC igniter. |
| | 14. | PAD-E | Install control battery and safety wire. |
| | 15. | PAD-M | Ready $LN_2$ equipment. |
| | 16. | PAD-M | Adjust fin clamps to launch position. |
| T-390 | 1. | PAD-M | Torque turbine. |
| | 2. | CTC | Verify completion of capsule ordnance connection. |
| | 3. | C | Reset flight sequencer. |
| T-385 | 1. | PAD-E | Make final check of 400 cycle inverter frequency and voltage adjustment. |
| | 2. | PAD-E | Make functional check of precooling motor operation. |
| | 3. | M | Safety wire DCR switches. |
| T-380 | 1. | PAD-CAP | Verify helium fill. |
| | 2. | C, GEN | Check voltage clear (control voltage On and Off). |
| | 3. | PAD-M | Load $LN_2$ boom tank (booster). |
| | 4. | E | Cooling bypass On (Off after $LN_2$ is loaded). |
| | 5. | E | Automatic fill On. |
| | 6. | PAD-M | Torque turbine. |
| | 7. | ANNOUNCEMENT | All personnel not required for operation in the pad area should clear the area for destruct block connection. |
| | 8. | BH | Verify vehicle RF silence. |
| | 9. | PAD-E and PAD-SAFETY | Electrically connect booster cable to destruct block. |
| | 10. | M | Verify destruct safe (light). |
| | 11. | PS | Verify destruct safe (light). |

| | | | |
|---|---|---|---|
| T-380 (Cont.) | 12. | PAD-SAFETY | Pull mechanical arming pin on destruct block and clear aft section. |
| | 13. | PAD-M | Secure destruct access door for flight. |
| | 14. | PAD-E | After no-voltage check remove all structure-utility room over-all test cables. |
| | 15. | PAD-M | Secure recovery doors for flight. |
| T-360 | 1. | PAD-M | Close aft section doors III-IV and I-II. |
| T-350 | 1. | PAD-M | Close instrument compartment doors (do not secure door III). |
| | 2. | E | Normal cooling switch On. |
| | 3. | E | Blower On. |
| | 4. | MEAS | Monitor instrument compartment temperature. |
| T-345 | 1. | CTC | Call capsule personnel on station. |
| | 2. | PAD-E and PAD-M | Final vertical alignment. |
| | 3. | PAD-CAP | Verify disconnect of peroxide lines at capsule and trailer. |
| T-330 | 1. | PAD-CAP | Capsule interior check. |
| T-325 | 1. | PAD-PAA | Open platform No. 2. |
| | 2. | ANNOUNCEMENT | All operational personnel standby to clear to the blockhouse for RF test; all nonoperational personnel clear the area immediately. |
| | 3. | PAD-PAA | Position and secure outrigger (on west side of structure for clearance of power post). |
| | 4. | PAD-PAA | Open platform No. 4. |
| | 5. | PAD-M | Drop No. 2 mast bunge to ground level. |
| T-320 | 1. | PAD-M | Close water valves 1, 3, and 4, and open valve 2. Disconnect both safety showers and disconnect water supply line at back of structure. |
| | 2. | PS | Establish road blocks and clear area of non-operational personnel for RF test. |
| | 3. | PAA-CAP | Install GSE hatch. |

| | | | |
|---|---|---|---|
| T-315 | 1. | PAD-PAA | Open platform No. 3. |
| T-316 | 1. | PAD-M | Disconnect structure pneumatic supply at service pipe 3. |
| | 2. | PAD-PAA | Move service structure to edge of pad. |
| T-305 | 1. | TC | Announce for photo and searchlight crews to clear area. |
| | 2. | TC | Announce for personnel behind blockhouse to come into the blockhouse. |
| T-300 | 1. | C | Control voltage On (voltage clear). |
| | 2. | G | Gyros On. |
| | 3. | G | Erection On. |
| | 4. | RF | Verify DOVAP reference transmitter On. |
| | 5. | PAD-M | Engine control regulator to zero psig. |
| T-298 | 1. | G | Amplifiers On. |
| | 2. | TC | Reset TC panel. |
| T-295 | 1. | ALL PERSONNEL | Clear pad to blockhouse for RF interference test. |
| | 2. | RANGE | Standby for all RF systems check. |
| | 3. | PS | Report to test conductor as soon as area is clear. |
| | 4. | PAD-M | Make remote operational check of service structure from blockhouse. |
| | 5. | M | RF silence Off. |
| | 6. | M | Cut safety wire On DCR switches. |
| | 7. | BH-CAP | Apply capsule power. |
| | 8. | PS | Squib arming switch On (pad cleared position). |
| | 9. | ANNOUNCEMENT | Caution all personnel, capsule abort system arming will be accomplished.<br>Station Rogers:<br>a. Blockhouse abort box (Dr. Debus).<br>b. MERCURY control center.<br>c. Capsule control panel.<br>d. Pad safety.<br>e. SRO.<br>f. Flight safety. |

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|---|---|---|---|
| T-295 (Cont.) | 10. | CTC | Arm the squib bus. |
| | 11. | TC | Verify proper arm indications on TC panel. |
| T-290 | 1. | RANGE | C- and S-band radars On. |
| | 2. | BH-CAP | Proceed with all RF components tests. |
| | 3. | RANGE | AZUSA ground station reading. |
| | 4. | M | AZUSA On. |
| | 5. | RANGE | Readout AZUSA and report completion to TC. |
| | 6. | RANGE | Command carrier On. |
| | 7. | M | Telemeter On. |
| | 8. | M | Calibrator On. |
| | 9. | C | Control computer On. |
| | 10. | M | DOVAP On. |
| | 11. | RF | Begin check of DOVAP and Beat-Beat. |
| T-285 | 1. | BH | Sequence and E-1 recorders to minute speed. |
| | 2. | BH | Recorder time pulse On. |
| | 3. | M | DCR No. 1 On. |
| | 4. | M | DCR No. 2 On (allow at least 30-second warmup). |
| | 5. | C | Program device On. |
| | 6. | C | Rudder drive On. |
| | 7. | C | Verify servo voltage ok (light On). |
| | 8. | P | Verify voltage ok (light On). |
| | 9. | AXN | Power transfer test On and Off (momentarily). |
| | 10. | SEQ | Record all battery voltages. |
| | 11. | G | Simultaneous control commands On and Off. |
| | 12. | L | Network roger of satisfactory power transfer. |
| | 13. | AXN | Emergency booster power Off (verify). |
| | 14. | C | Rudder drive Off. |
| | 15. | C | Program device Off. |
| | 16. | C | Control computer Off. |
| | 17. | RANGE | Cutoff command. |
| | 18. | RANGE | Destruct command. |
| | 19. | RANGE | Switch transmitters. |

| | | | |
|---|---|---|---|
| T-285 (Cont.) | 20. | RANGE | Cutoff command. |
| | 21. | RANGE | Destruct command. |
| | 22. | M | DCR No. 1 Off. |
| | 23. | M | DCR No. 2 Off. |
| | 24. | RANGE | Secure command carrier. |
| T-280 | 1. | ALL RF MONITORING STATIONS | Report any nonflight tolerable type RF interference to the blockhouse. |
| | 2. | M | Secure booster RF equipments as individual systems complete their tests. |
| T-275 | 1. | TC | Receive status report of all uncompleted RF checks. |
| T-270 | 1. | TC | Check that all RF equipments have been secured. |
| | 2. | CTC | Disarm squib bus. |
| | 3. | PS | Open squib arming switch (pad Not cleared position). |
| | 4. | M | Safety wire DCR switches. |
| | 5. | ANNOUNCEMENT | Capsule abort system disarmed. |
| | 6. | ANNOUNCEMENT | Operational personnel return to vehicle after power is removed from capsule. |
| | 7. | G | Secure gyros. |
| T-265 | 1. | PAD-M | Engine control regulator to 605 psig. |
| | 2. | PAD-PAA | Move service structure around vehicle. |
| | 3. | TC | Establish complex and vehicle RF silence. |
| | 4. | M | RF silence switch On. |
| | 5. | PAD-CAP | Capsule personnel return to structure. |
| | 6. | E | Instrument compartment cooling Off. |
| | 7. | E | Bypass On, blower Off. |
| | 8. | MEAS | Monitor instrument compartment temperature. |
| | 9. | PAD-M | Reconnect water supply line at back of structure. |
| | 10. | PAD-M | Reconnect safety shower on west side. |
| | 11. | PAD-M | Open water valves 1 and 4. |
| | 12. | PAD-M | Reconnect structure pneumatic supply. |

Part II - Launch Countdown (Cont.)

| | | | |
|---|---|---|---|
| T-260 | 1. | PAD-PAA | Close platform 2, 3, and 4. |
| | 2. | PAD-CAP | Reconnect capsule peroxide lines to capsule and trailer. |
| T-255 | 1. | PAD-CAP | Open capsule door. |
| T-250 | 1. | PAD-CAP | Switch change and power up. |
| | 2. | PAD-M | Open instrument compartment door III (when internal temperature reaches near ambient). |
| | 3. | PAD-M | Apply pressure to booster and capsule masts. |
| | 4. | P | Verify mast pressures. |
| T-245 | 1. | PAD-CAP | Begin control system nozzle static firing. |
| T-200 | 1. | PAD-M | Bring LOX trailers into position and connect. |
| | 2. | PAD-M | Bring tail heater into position. |
| | 3. | PAD-M | Install LOX vent pipe. |
| | 4. | PAD-M | Remove fuel flex overflow line. |
| | 5. | PAD-PAA | Open platform 1. |
| | 6. | PAD-M | Connect fuel bubbling and start flow. |
| | 7. | PAD-M | Make final torque check on LOX manhole bolts. |
| | 8. | MEAS | Last minute checks of blockhouse measuring system. |
| | 9. | PAD-MEAS | Check that all hand valves on calibration panel are in proper position for firing and secure. |
| | 10. | PAD-M | Locate LOX topping trailer. |
| | 11. | PAD-M | Connect electrical cables to LOX topping trailer. |
| | 12. | PAD-M | Remove plug-in steam exhaust. |
| | 13. | PAD-M | Remove LOX pump bearing purge. |
| | 14. | PAD-M | Small heater on alcohol manifold. |
| T-190 | 1. | TC | Launch weather decision prior to LOX loading. |
| T-180 | 1. | P | Weight measurement prior to LOX and $LN_2$ loading (clear vehicle when announcement is made to TC). |

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|---|---|---|---|
| T-180 (Cont.) | 2. | P | LOX valve heater On. |
| | 3. | PAD-M | Start LOX precooling and loading sequence. |
| | 4. | MEAS | Monitor LOX tank pressure. |
| T-165 | 1. | CTC | Verify astronaut has left Hangar S. |
| T-145 | 1. | P and PAD-M | End LOX tanking. |
| | 2. | P | Weight measurement after LOX tanking. |
| | 3. | P | LOX topping to automatic. |
| T-140 | 1. | PAD-CAP | Verify astronaut arrival at pad. |
| | 2. | PAD-CAP | Terminate static firing of peroxide nozzles. |
| | 3. | PAD-CAP | Capsule switch check. |
| T-135 | 1. | PAD-PAA | Remove LOX trailers. |
| | 2. | PAD-M | Tail heater On. |
| | 3. | PAD-M | Install sheet metal cover on LOX manhole. |
| | 4. | PAD-E | Prepare LEV-3 equipment for final azimuth check. |
| | 5. | PAD-M | Move booster $H_2O_2$ truck into position. |
| T-130 | 1. | PAD-CAP | Pre-purge suit circuit. |
| | 2. | PAD-M | Install thrust chamber igniter. (Do not connect electrically.) |
| | 3. | PAD-E and PAD-M | Perform launch azimuth check. |
| T-125 | 1. | TC | Ascertain that all vehicle systems are Go and all preparations are on schedule. If affirmative, proceed with astronaut installation. If negative, a hold should be absorbed at this time prior to astronaut installation. |
| T-123 | 1. | CTC | Proceed with astronaut insertion. |
| T-120 | 1. | P | Turn $H_2O_2$ heaters On. |
| | 2. | MEAS | Monitor $H_2O_2$ tank temperature (redline values: below 70°F, above 90°F). |
| | 3. | PAD-M | Check operation of $H_2O_2$ heaters (booster). |
| | 4. | PAD-M | Start booster $H_2O_2$ loading (booster). |
| T-115 | 1. | PAD-CAP | Suit purge. |

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| T-105 | 1. | PAD-CAP | Suit pressure check. |
| T-100 | 1. | PAD-M and P | Check LOX topping computer operation. |
| | 2. | PAD-M | Verify No. 1 mast eject line connected. |
| | 3. | PAD-M | Close last instrument compartment door and secure for flight (after LEV-3 azimuth check). |
| | 4. | PAD-E, PAD-M, and M | Instrument compartment cooling On when last door is in place. |
| | 5. | E | Normal cooling switch On. |
| | 6. | E | Blower On. |
| | 7. | MEAS | Monitor instrument compartment temperature. |
| | 8. | PAD-M | End $H_2O_2$ loading. |
| T-95 | 1. | ANNOUNCEMENT | All nonoperational personnel clear the area. |
| | 2. | PAD-M | Clip safety wire from No. 2 mast release. |
| | 3. | PAD-M | Adjust and connect capsule umbilical lanyard. |
| | 4. | PAD-M | Make gas evolution check on $H_2O_2$ system. |
| | 5. | PAD-CAP | Harness and cabin inspection. |
| T-90 | 1. | PAD-M | Move LOD $H_2O_2$ truck out of immediate area. |
| | 2. | PAD-M | Verify No. 2 mast eject control line connected. |
| | 3. | PAD-CAP | Install capsule hatch. |
| T-85 | 1. | PAD-PAA | Open platform 2. |
| | 2. | PAD-M | Close water valves 1 and 2 and open 3. |
| | 3. | PAD-M | Disconnect safety shower and stow for launch. |
| | 4. | PAD-M | Disconnect water supply line at back of structure and secure. |
| | 5. | PAD-CAP | Capsule purge. |
| | 6. | PAD-E | Check mainstage stick (short momentarily at pad). |
| T-80 | 1. | PAD-M | Secure drain screw in combustion chamber. |
| | 2. | PAD-M | Install ignition sensing stick and resistance check (do not connect). |
| | 3. | PAD-M | Torque turbine. |
| | 4. | PAD-M | Remove fueling scaffold. |

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| T-80 (Cont.) | 5. | PAD-M | Check "check valve" operation in pneumatic systems. |
| | 6. | PAD-E | Open two lids on trench near blockhouse and install safety ropes. |
| | 7. | PAD-PAA | Open $CO_2$ valve in utility room. |
| | 8. | PAD-PAA | Verify platform 1 open. |
| | 9. | PAD-M | Move spare parts trailer. |
| | 10. | PAD-CAP | Gas sampling. |
| | 11. | PAD-CAP | Move transfer van to launch position. |
| T-75 | 1. | PAD-CAP | Capsule pressure check. |
| T-70 | 1. | PAD-M | Make final check of engine control pressure regulator and secure for launch (redline 655 psig maximum, 585 psig minimum). |
| T-65 | 1. | PAD-M and E | Turn on $P_c$ switch heaters and transducer heater and confirm operation. |
| | 2. | PAD-PAA | Open platform 4. |
| T-60 | 1. | PAD-PAA | Open platform 3. |
| | 2. | PAD-M | Disconnect and secure structure pneumatic supply. |
| | 3. | TC | Obtain clearance from all stations to remove structure to edge of pad. |
| | 4. | PAD-PAA | PAA high pressure personnel in phone circuit for setting up of high pressure system for tail purge. |
| | 5. | PS | Check hold fire and first motion circuitry. |
| | 6. | C | Control voltage On. |
| | 7. | G | Gyros On. |
| | 8. | G | Erection On. |
| | 9. | PAD-CAP | Clear service structure. |
| | 10. | PAD-M | Transfer $LN_2$ trailers. |
| T-57 | 1. | G | Amplifier On. |
| | 2. | TC | Reset TC panel if required. |
| T-55 | 1. | PAD-M | Set up red and blue high pressure storage systems for launch. |

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| T-55 (Cont.) | 2. | PAD-M | Set up ground regulator to 3000 psig for tail purge. |
| | 3. | PAD-PAA | Move structure to edge of pad and ready remote controls. |
| | 4. | PAD-M | Close tails spheres bypass hand valve. |
| | 5. | PAD-M | Set up 3100 psig to valve box. |
| | 6. | PAD-M | Set ignition regulator to psig. |
| | 7. | PAD-M | Open igniter bottle pressurizing hand valve. |
| | 8. | PAD-M | Torque turbine. |
| | 9. | PAD-M | Monitor remote operation of cherry-picker before placement next to capsule. |
| | 10. | CP | Position cherry-picker for emergency egress operation and station operator in blockhouse. |
| T-50 | 1. | PAD-M | Disconnect line from injector purge coupling. |
| | 2. | PAD-M | Connect ignition sensing stick to valve box. |
| | 3. | C | Rudder drive On and Off for control check. |
| | 4. | M-113 | Verify the M-113 emergency egress vehicle is on station. |
| T-45 | 1. | PAD-M | Remove tail heater and secure for launch. |
| | 2. | PAD-M | Close tail doors I-II. |
| | 3. | PAD-M | Move LOD shop truck to launch location. |
| | 4. | PAD-M | Connect capsule mast bunge cord (G: Observe phi pitch meter for amount of disturbance - missile over 1). |
| | 5. | PAD-M | Check that capsule mast 750 supply hand valve is full open. Check that compartment mast 750 supply hand valve is full open. |
| | 6. | PAD-M | Make last check of cable mast supply ground regulator. |
| | 7. | PAD-CAP | Clear utility room. |
| T-40 | 1. | PAD-M | Check only the following hand valves in the valve box are open:<br>a. Regulator inlet.<br>b. Igniter bottle pressurizing. |
| | 2. | PAD-M | Remove last scaffold. |

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| T-40 (Cont.) | 3. | PAD-SAFETY | Remove all nonauthorized vehicles from rear of blockhouse. |
| | 4. | PAD-E | TC igniter cable check. |
| | 5. | PAD-M | Disconnect fuel bubbling and install cap on coupling. |
| | 6. | PAD-M | Close tail door III-IV. |
| T-35 | 1. | ANNOUNCEMENT | All personnel not stationed in the blockhouse for launch, clear the area to launch location. |
| | 2. | CTC | All capsule systems go verification. |
| | 3. | PAD-M | Connect igniter squib to valve box. |
| | 4. | PAD-M | Close utility room door and secure for flight. |
| T-33 | 1. | PAD - ALL PERSONNEL | Clear area to blockhouse. |
| T-30 | 1. | PS | Verify complex area is clear and RF silence may be lifted. |
| | 2. | M | RF silence switch Off. |
| | 3. | MEAS | Check that all brown recorders are On. |
| | 4. | C | Control computers On. |
| | 5. | CTC | Functional check of hold fire. |
| | 6. | M | DOVAP On. |
| T-29 | 1. | RANGE | Standby for radar beacon checks C- and S-band radars away from pad. |
| T-25 | 1. | CTC | All RF systems On. |
| | 2. | CTC | C- and S-band beacons On. |
| | 3. | PS | Squib arming switch On (when complex area is Safe). |
| | 4. | ANNOUNCEMENT | Capsule abort system is to be armed. |
| | 5. | RF | DCR monitor receiver On. |
| | 6. | RANGE | Command carrier On. |
| T-24 | 1. | M | Telemeter On. |
| | 2. | M | Calibrator On. |
| T-22 | 1. | M | Recorder transfer On and Off as request for telemetry check. |
| | 2. | CTC | Arm capsule squib bus. |

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| T-22 (Cont.) | 3. | CTC | Verify abort disarm switch in manual position. |
| | 4. | ANNOUNCEMENT | Capsule abort system armed. |
| | 5. | ABTL | Verify abort armed (light On). |
| T-20 | 1. | P | Tail purge On. |
| | 2. | M | AZUSA On. |
| T-18 | 1. | RANGE | AMR telemeter check. |
| | 2. | AB | LOD telemeter check. |
| T-16 | 1. | C | Meter range On. |
| | 2. | C | Rudder drive On. |
| | 3. | | Simultaneous command On and Off. |
| | 4. | C | Rudder drive Off. |
| T-15 | 1. | TC | Obtain Dr. Debus' ok for launch. |
| | 2. | CTC | Begin transfer of capsule to internal power. |
| | 3. | M | Cut safety wire on DCR switches. |
| T-14 | 1. | M | Preflight calibrator to 0 percent. |
| | 2. | M | Calibrator Off. |
| T-12 | 1. | M | Preflight calibrator to 100 percent. |
| T-10 | 1. | P | Pressurize missile spheres to 3000 psi. |
| | 2. | M | Calibrator On. |
| | 3. | C | Rudder drive On and Off. |
| | 4. | M | Preflight calibrator Off. |
| | 5. | MEAS | Ground measuring voltage minus in blockhouse momentarily. |
| T-9 | 1. | M | Preflight calibrator Off (left side). |
| | 2. | M | Calibrator Off. |
| | 3. | MEAS | Verify 100 cps oscillator is set up. |
| T-8'45" | 1. | RANGE | Telemeter recording On. |
| | 2. | AB | Telemeter recording On. |
| | 3. | M | Preflight calibrations as follows: From Off to oscillator and pause 5 second CEC recorders On. In 1 second intervals oscillator |

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| T-8'45" (Cont.) | | | to 0 to 10 to 20 to 30 to 40 to 50 to 60 to 70 to 80 to 90 to 100 to 0 percent. |
| | 4. | M | Calibrator On. |
| | 5. | M | Forced calibration On and Off. |
| | 6. | RANGE | Telemeter recording Off. |
| | 7. | AB | Telemeter recording Off. |
| | 8. | M | Preflight calibrator Off. |
| | 9. | BH-PAA | Remotely move structure to launch position. |
| T-7 | 1. | M | Command receiver No. 1 On. |
| | 2. | M | Command receiver No. 2 On. |
| T-6 | 1. | P | Check that LOX topping is on schedule. |
| | 2. | SEQ | Sequence and E&I recorders minute speed. |
| | 3. | SEQ | Time pulse On. |
| | 4. | C | Program device On. |
| | 5. | GEN | Check voltage adjustments. |
| T-5 | 1. | C | Rudder drive On (prep complete). |
| | 2. | P | Verify voltage ok (light On). |
| | 3. | AXN | Power transfer test switch On momentarily. |
| | 4. | G | Simultaneous commands On and Off. |
| | 5. | RANGE | Cutoff command. |
| | 6. | L | Network roger satisfactory power transfer. |
| | 7. | AXN | Emergency booster power Off. |
| | 8. | C | Rudder drive Off. |
| | 9. | G | Check LEV-3 gyro position indications. |
| | 10. | C&G | Clear signal from control and gyro panel. |
| T-4 | 1. | TC | Check stations for proper indications.<br>a. Power panel (P).<br>b. Measuring panel (M).<br>c. Autopilot rack (G&C).<br>d. Capsule test conductor (all capsule indications).<br>e. Blockhouse measuring (MEAS).<br>f. Sequence recorders (SEQ).<br>g. Telemeter station Hangar D (AB). |

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| T-4 (Cont.) | | | h. Pad safety (PS). |
| | | | i. BH-PAA (service structure secure). |
| | | | j. Aeromedical. |
| T-2'30" | 1. | P | Selector switch to launch. |
| | 2. | M | Arm destruct package. |
| | 3. | PS | Note destruct armed and close hold fire. |
| | 4. | CTC | Final clearance from capsule. |
| | 5. | CP | Remove cherry-picker to launch position. |
| T-2 | 1. | M | Block booster abort Off. |
| | 2. | C | Rudder drive On. |
| | 3. | P | Verify ready to fire (indication). |
| | 4. | G | Simultaneous commands. |
| | 5. | RANGE | Telemeter recording On. |
| | 6. | BH-CAP | Proceed with telemeter preflight calibrations. |
| T-60" | 1. | RANGE | Give mark to range at 60 seconds. |
| | 2. | P | LOX topping Off. |
| | 3. | AB | LOD telemeter recording On. |
| T-50" | 1. | BH-CAP | Freon flow cutoff. |
| T-47" | 1. | SEQ | Sequence recorders fast speed. |
| T-35" | 1. | P | Firing command. |
| | 2. | ALL STATIONS | Verify automatic sequence as major items occur. |
| | 3. | CTC | Announce "Capsule umbilical dropped." |
| | 4. | CTC | Announce "Periscope door closed." |
| | 5. | P | Announce "Vent valves closed." |
| | 6. | P | Announce "Fuel tank pressurized." |
| | 7. | MEAS | Announce "LOX tank pressurizing." |
| | 8. | P | Announce "LOX tank pressurized." |
| (T-14") | 9. | GEN | Announce "Missile power." |
| | 10. | P | Announce "Boom drop." |
| | 11. | P | Announce "Ignition." |
| | 12. | P | Announce "Mainstage." |
| T-0 | 1. | P | Announce "Liftoff." |

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| T+0 | 1. RANGE | Liftoff. |
| | 2. RANGE | Clock start. |
| | 3. RANGE | Call out time in 10 second increments until T+180, in 30 second increments until termination. |
| | 4. BH | All personnel except Launch Director remain in place during flight. |
| T+5 | 1. BH | Sequence recorders Slow. |

TEST TERMINATION

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|---|---|---|
| | 1. PAD-M | Secure high pressure $GN_2$. |
| | 2. PAD-PAA | Close $CO_2$ bottles. |
| | 3. P | Vent $CO_2$ line. |
| | 4. PAD-M | Secure LOX topping and $LN_2$ trailers. |
| | 5. GEN | Secure ground generators. |

Explanation of code used in countdown.

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|---|---|
| AB | Telemeter station hangar D (booster) |
| ABT | Blockhouse abort panel (Dr. Debus' panel) |
| AXN | Auxiliary network panel |
| BH | Blockhouse (miscellaneous operations) |
| BH-CAP | McDonnell, NASA, and Aeromedical |
| BH-PAA | Pan American pad operations |
| C | Control panel |
| CP | Mobile cherry-picker tower |
| CTC | Capsule test conductor |
| E | Environmental control panel (booster) |
| G | Gyro panel |
| GEN | Generator panel |
| I | Inverter panel |
| L | Recorder light panel |
| M | Measuring panel |
| MEAS | Blockhouse measuring (booster) |
| M-113 | Emergency rescue vehicle |
| P | Propulsion panel |
| PAD-CAP | McDonnell and NASA pad capsule operations |

| | |
|---|---|
| PAD-E | G&C, network pad operations |
| PAD-M | Fueling, propulsion, mechanical pad operations |
| PAD-MEAS | Measuring pad operations |
| PAD-PAA | Pan American pad operations |
| PAD-SAFETY | Pad safety (PAA) pad operations |
| PD | Program device rack |
| PS | Pad safety panel (blockhouse) |
| RANGE | Items handled through central control to remote range stations |
| RF | Blockhouse and remote RF system (booster) |
| SEQ | Blockhouse function recorders (SEQ, voltage, current) |
| TC | Test conductor panel (vehicle) |

## 7.3 EMERGENCY EGRESS OPERATIONS

### 7.3.1 ORGANIZATION OF RESPONSIBILITIES

#### 7.3.1.1 General

Responsibility for the protection and safety of personnel on the AMR and surrounding areas was governed by standard pad safety and range safety regulations. The responsibility for the protection, safety, and rescue of the astronaut was vested in NASA.

To provide maximum safety to the astronaut during all phases of the launch and flight, and to cover every conceivable emergency situation, the areas in proximity to the flight path of the vehicle were divided into recovery sectors.

#### 7.3.1.2 Launch Pad Area

This area consisted of all the facilities inside the fence of Complex 56, concerned primarily with providing emergency egress for the astronaut. A Pad Area Rescue Squad (PARS) was organized to accomplish this task. The PARS was responsible to the launch director until liftoff or until capsule separation if an off-the-pad abort occurred. Rescue operations on the pad were conducted under supervision of the launch director, and recovery, if capsule flight occurred, was under the direction of the launch site recovery commander.

### 7.3.1.3 Launch Site Recovery Area

This area consisted of all the land area from four nautical miles uprange of the pad to 12 nautical miles downrange of the pad along the flight line including the water area immediately offshore of the Cape as well as the Banana River. Responsibility for this area was delegated to the launch site recovery commander.

### 7.3.1.4 Downrange

Downrange consisted of the range area from approximately 12 nautical miles offshore downrange of the Cape, to the predetermined normal capsule recovery area, with a 24-nautical-mile wide corridor. Responsibility for the operations within this area was delegated to the United States Navy Recovery Task Force Commander.

## 7.3.2 RESCUE OPERATIONS TIME STUDY

Extensive time studies were made to determine which of the equipment available was best suited for each specific period of time in the countdown. The studies were divided into two major categories: one for the astronaut self-sustaining, and one for the astronaut incapacitated. Figure 7-4 is a compilation of the findings of these studies.

The basic rule predominant in the final selection of the methods employed was that a maximum security be provided for the astronaut with a minimum risk to rescue personnel. Three members of the rescue squad were involved in rescue operations requiring squad access to the capsule.

In Figure 7-4 the heavy bar indicates the time the astronaut would be exposed to a hazardous vehicle, and the shaded bar indicated the total man-seconds all personnel involved in the rescue would be exposed to a potentially hazardous booster. These time studies, therefore, aided in the selection of optimum methods for the guidelines established. Having selected the optimum methods, and considering the status of the vehicle and complex, a set of procedures were devised to cover the general type of major failures that could occur for eight combined vehicle-complex conditions. It was not feasible to preconceive and reduce to writing, rescue procedures for every remotely possible malfunction; therefore, the successful execution of a rescue operation was largely dependent upon the response, skills, and adaptability of the individuals affecting the operations.

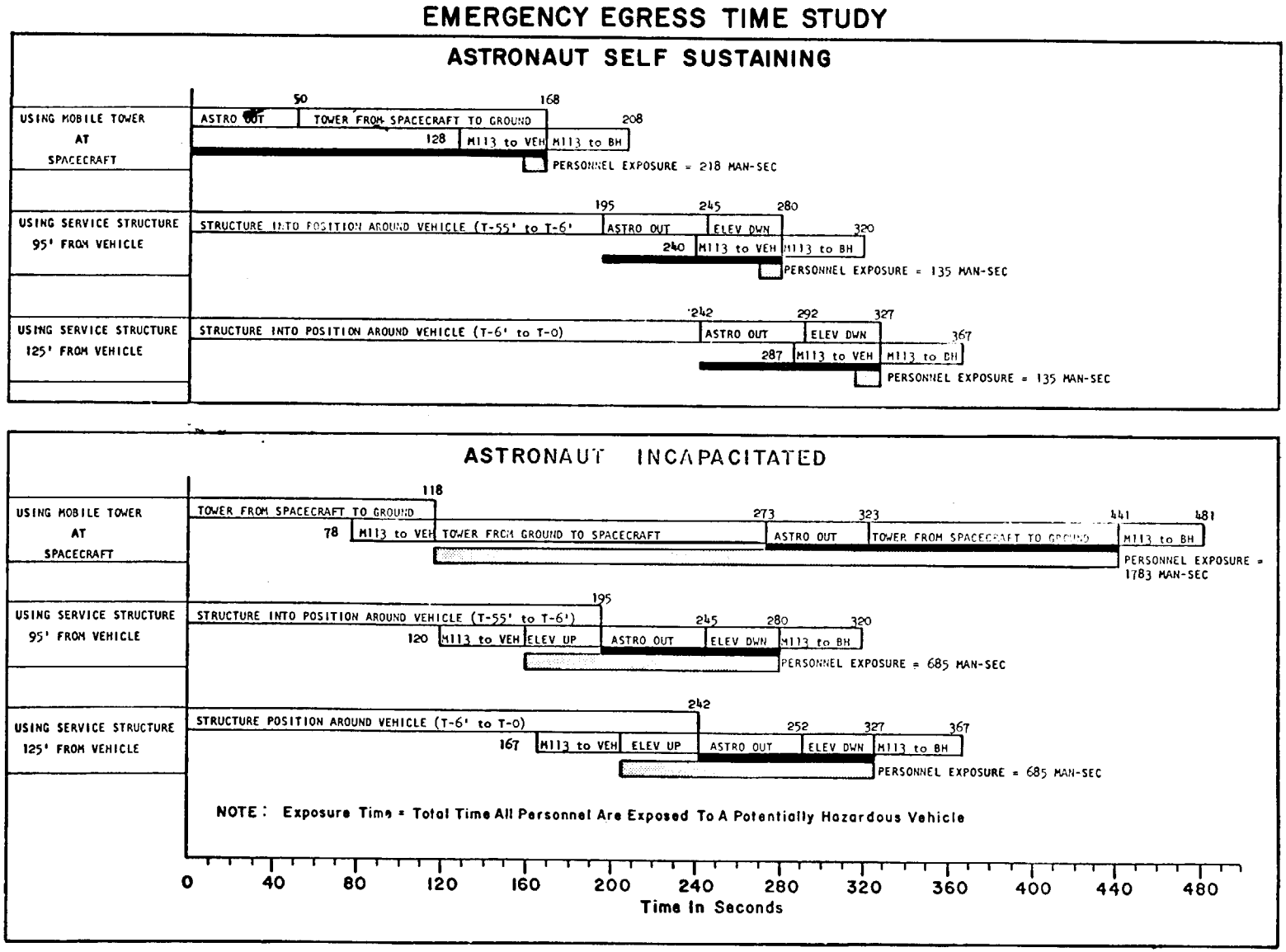



Figure 7-4. Emergency Egress Time Study

## 7.3.3 EMERGENCY EQUIPMENT

### 7.3.3.1 Mobile Aerial Tower

The mobile aerial tower, shown in Figure 7-5, was originally intended, by STG, to be used with the MERCURY-ATLAS. Because of desire to gain experience, and since time studies revealed it to be faster than the remote controlled structure under certain conditions, it was selected for egress of the self-sustaining astronaut after the service structure was removed from around the vehicle. The tower, cherry picker, was capable of reaching vertical heights of 125 feet. The tower cab was specially designed to be positioned next to the capsule hatch to provide the astronaut with a means of rapid self-egress, should booster or capsule conditions dictate such action. The tower could be controlled from a position on the ground at the rear of the truck-transporter, from within the tower cab, or could be lowered by remote programmed control from within the blockhouse. Special pushbutton switches which actuated a programmed descent away and down from the MERCURY-REDSTONE vehicle were installed in the tower cab and the blockhouse. The remote control pushbutton switch in the blockhouse was located on the service structure remote control panel. The cab of the mobile tower was positioned next to the capsule hatch when the service structure was removed from the vehicle, and it remained in this position until T-4 minutes of the countdown for emergency use by the astronaut.

### 7.3.3.2 M-113 Armored Personnel Carrier

The military M-113 armored personnel carrier was selected to provide transportation and limited protection for the PARS. The M-113 is capable of withstanding 12 psi overpressure, and it could provide limited protection against heat if the vehicle had to travel near or through the edge of a fire to reach the capsule. The M-113, a full track vehicle designed for cross country operation, is capable of traveling over the scrub terrain of the Cape at speeds of up to 35 miles per hour. It was specifically modified with the communications and miscellaneous equipment peculiar to these emergency operations listed as follows:

- Communications
  a. 30.3 mc transmitter and receiver.
  b. Aeromed net, UHF radio and receiver.
  c. Missile operational inter-phone system.
  d. Vehicle crew inter-phone system.
  e. Public address speaker.

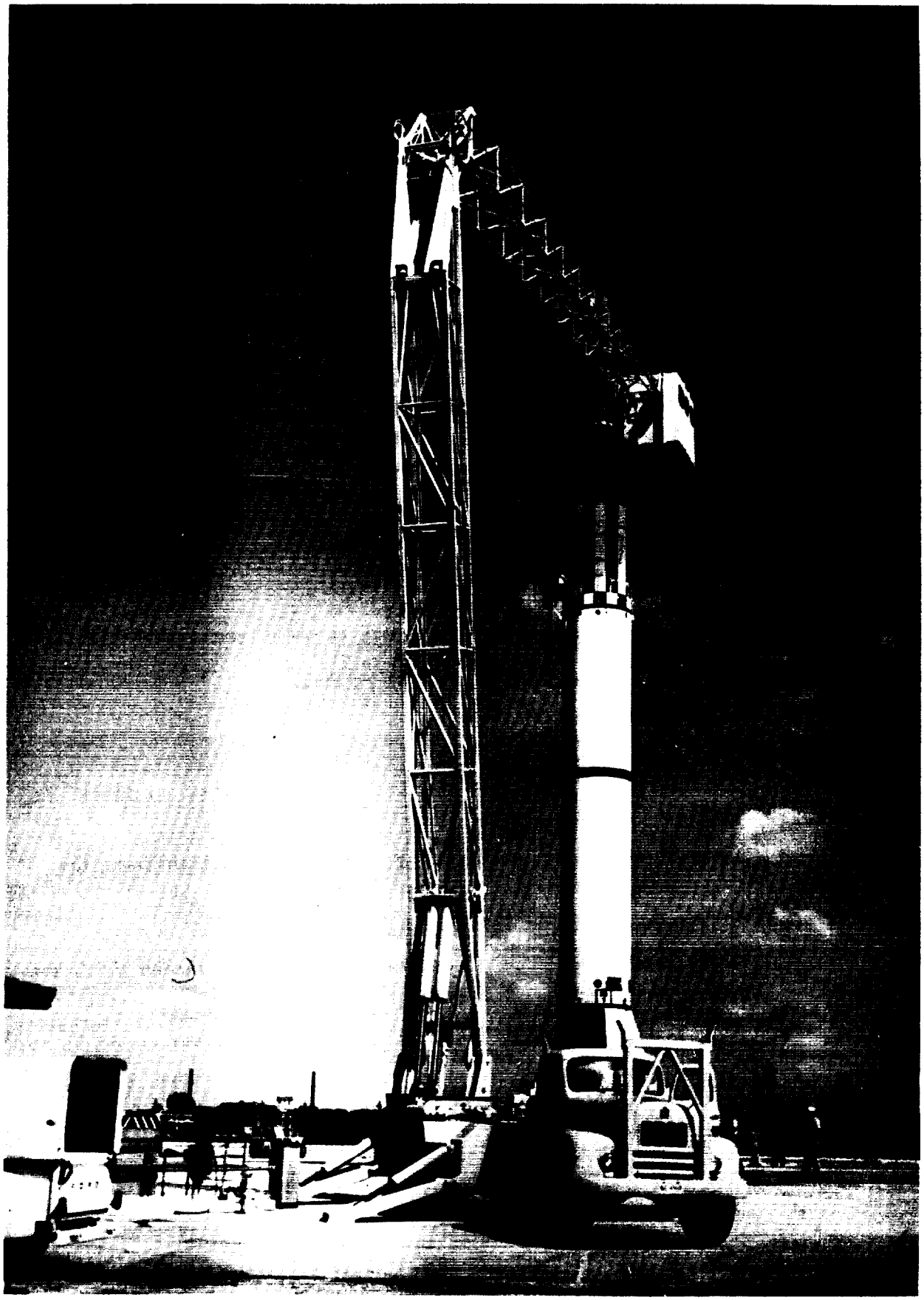


Figure 7-5. Mobile Tower (Cherry Picker)

- Auxiliary Equipment

  a. Vehicle pusher blade adapter.
  b. Shepards crook on 25 feet of wire cable.
  c. Crash helmets with earphones.
  d. Aluminized two-piece fire suits with boots.
  e. Scott Air Paks with five-minute bottles.
  f. Two fire entry suits.
  g. Special fire axe to provide hook aperture.
  h. Portable resuscitator.
  i. Heavy duty manual bolt cutter.

The members of the PARS, stationed in the M-113 armored personnel carrier during the countdown and launch, are listed below. The personnel of this crew were kept at a minimum to reduce the numbers exposed to a potential hazard:

- Vehicle commander.
- Medical doctor.
- Capsule technician.
- Two firemen (one M-113 driver).
- Mobile tower (cherry picker) operator.

In accordance with the egress procedures developed by the egress committee, the PARS was assigned the following functions:

- Perform emergency astronaut egress from the capsule while the booster was still in an erect position on the launch pad.
- Perform emergency recovery/rescue in the event of an off-the-pad abort or some abort condition wherein the capsule landed within the launch complex area.
- Assist, as requested by the launch site recovery commander, in recovery and/or rescue outside the launch complex area.

### 7.3.3.3 Emergency Equipment Location

The location of the emergency egress equipment, at approximately T-55 minutes, is shown in Figure 7-6. As illustrated, the service structure has been moved back to its launch position; the mobile tower cab has been positioned next to the capsule hatch; and the M-113 personnel carrier is moving in to embark the mobile tower operator

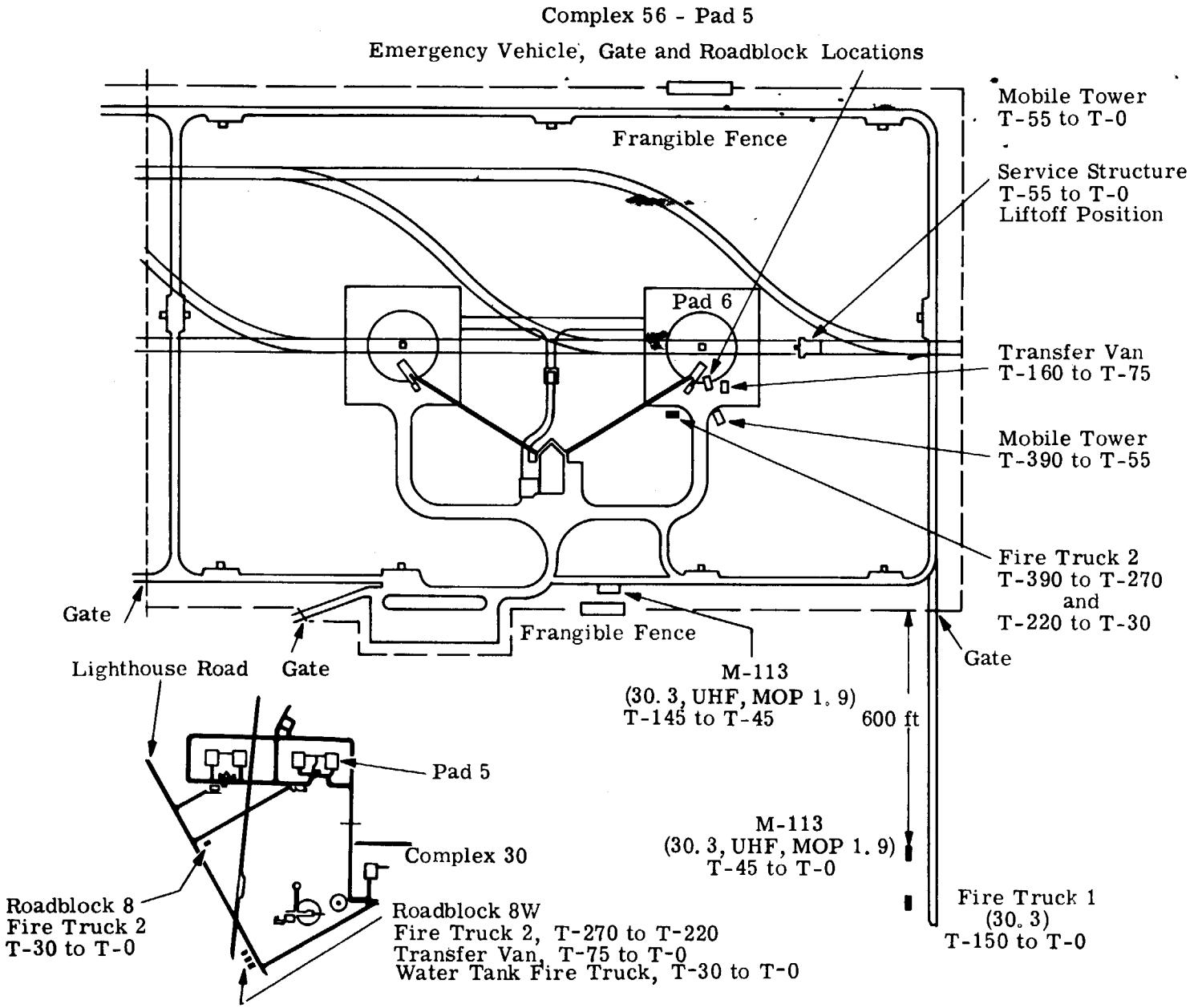



Figure 7-6. Diagram of Emergency Equipment Location for MERCURY-REDSTONE Launches, Complex 56, Pad 5

before proceeding to its launch position. The position of all the other emergency equipment, required for rescue and fire fighting for the periods from T-55 minutes to liftoff, is also shown.

## 7.4 RANGE SAFETY

### 7.4.1 RANGE SAFETY OFFICER (RSO) OPERATIONS

For ballistic vehicles, such as MERCURY-REDSTONE, the RSO had a plotting board display indicating the real time impact point, which was the point where the vehicle would impact if thrust termination occurred at the time of presentation. The data sources available to the IBM 7090 computer, or "Impact Predictor," were the C-band radars at the Cape, Patrick AFB, GBI, and the AZUSA Mark II at the Cape. The beat-beat system, developed by LOD, measured the phase difference of an airborne CW signal received by two antennas. These phase or beat differences were expressed in terms of the difference of the two slant ranges. Systems with their center line or zero beat line approximately 90 degrees to the flight line yield representations of the program and lateral deviations of the vehicle. These representations were presented on strip chart recorders for the RSO. AMR ELSSE (electronic skyscreen equipment) and NASA Beat-Beat MK II telemetry tracked one each of the vehicle's telemetry transmitters.

To protect life and property from an erratic vehicle, the Range Safety Division (RSD) of AFMTC required each vehicle launched from CCMTA to carry two independent command systems capable of terminating powered flight and/or destroying the vehicle. Two ARW-19 command receivers were carried in the MERCURY-REDSTONE boosters for range safety. Command transmitters were standing by at Cape Central Control, at Cape Command Destruct Transmitter Site, and GBI station 3. For the RSO's surveillance, real-time plotting board displays of the vehicle positions were provided in terms of ground range versus cross range (ground trace), ground range versus altitude (program profile), and altitude versus cross range (lateral profile). The data source for each position plotting board could be switched, during flight if necessary, between C-band and S-band radars on the Cape, and C-band radars at Patrick AFB and GBI in accordance with the prescribed range safety plan.

### 7.4.2 ABORT CONSIDERATIONS

A three-second period between an abort initiated by range safety cutoff command and fuel dispersion (destruct) command was requested by STG. This three-second period assured that a sufficient separation existed between the spacecraft and exploding

booster. RSD accepted a 105-degree launch azimuth and the requirement for the three-second separation time with the understanding that the destruct corridor would be correspondingly decreased along the southern impact line. RSD concurred in the allocation of abort command responsibility to the blockhouse (to T+8 seconds), the MERCURY Control Center, and the astronaut. RSD requested, however, that a stability analysis be made to ascertain how long the booster would fly if the capsule were aborted in flight. Subsequent agreements resulted in the incorporation of special provisions during the first period of flight wherein an abort command, during the initial 30 seconds of flight, would not cause a booster cutoff command except at the discretion of RSD. This provision assured that if an abort were given for spacecraft reasons a good booster could continue in powered flight to a safe impact area.

### 7.4.3 LAUNCH AZIMUTH CONSIDERATIONS

The original MERCURY-REDSTONE launch azimuth of 105 degrees was selected on the basis of minimum overland time, adequate distance from downrange islands (including all dispersions), optimum tracking coverage, nonhazardous Cape impact locations, and suitable recovery areas. This selection was also based on analysis of prevailing winds in the launch area and the development of a system of interchangeable escape rockets with different directions of lateral displacement.

While the RSD concurred in a 105-degree launch azimuth, they had originally stated a preference for a flatter trajectory (to reduce time over land) and a 100-degree azimuth; prior to the MERCURY-REDSTONE flight MR-2, LOD, STG, and the RSD agreed to a flatter trajectory (which initiated the tilt program earlier in flight). As a consequence, flights MR-2 and MR-BD were launched on an azimuth of 105 degrees utilizing the flatter trajectory.

In the interval between the MR-BD and MR-3 launches, however, RSD investigated the azimuth problem in further detail and discovered that, except for the early launch phase, a three-sigma right deviation trajectory for flight MR-3 would violate the range safety criteria, as imposed on the radar present-position plot (X-Y plot). Inasmuch as the scheduled launch of MR-3 was too close at hand for an azimuth change, a waiver was requested to allow the three-sigma right deviation trajectory. RSD indicated a willingness to grant the waiver if the launch agency agreed to change the azimuth to 100 degrees for all subsequent MERCURY-REDSTONE launches. STG concurred on this azimuth change for the MR-4 launch.

### 7.4.4 IMPLEMENTATION

Having established the methods, a set of procedures was prepared. This document was entitled Emergency Handbook for Pad Area Rescue. It was issued prior to the flight of MR-3, recalled and updated, and reissued for the flight of MR-4. The document defined, in sequential steps, the action necessary to cope with a preconceived emergency and identified by title the personnel responsible for each action. In the preparation of these procedures, detailed studies on the booster, the capsule, AMR, and Complex 56 GSE were made by the emergency egress committee. These procedures were subsequently translated into the MERCURY-ATLAS program by changing booster procedures and substituting the egress tower for the mobile serial tower which proved impractical for the MERCURY-ATLAS operation.

## 7.5 SPECIAL LAUNCH FACILITIES AND DISPLAYS

### 7.5.1 SERVICE STRUCTURE

#### 7.5.1.1 General

Prior to its use in the MERCURY-REDSTONE Program, the service structure on VLF 56, shown in Figure 7-7, was used for the launching of REDSTONE, JUPITER, and JUPITER-C launch vehicles. In order to accommodate the MERCURY-REDSTONE vehicle, a number of major modifications to the structure were required which are explained in the following paragraphs.

#### 7.5.1.2 White Room

Level three of the service structure was the area utilized for checkout and preparation of the MERCURY capsule. The capsule was mechanically mated to the booster approximately two weeks prior to launch. During this period of checkout and preparation, it was necessary to remove the capsule hatch for many of the checks. In reviewing the onboard capsule films taken on the first two successful unmanned flights (MR-1A and MR-2), it was discovered that a considerable amount of dust and other debris, apparently carried into the capsule during preflight checks, was floating about inside the capsule during the period of weightlessness. In February 1961, LOD was requested to explore the possibility of enclosing and air conditioning the capsule on level three of the service structure. Design requirements were as follows:

- Panels withstand 55 mile per hour winds.
- Panels be readily removable for winds exceeding 55 miles per hour.

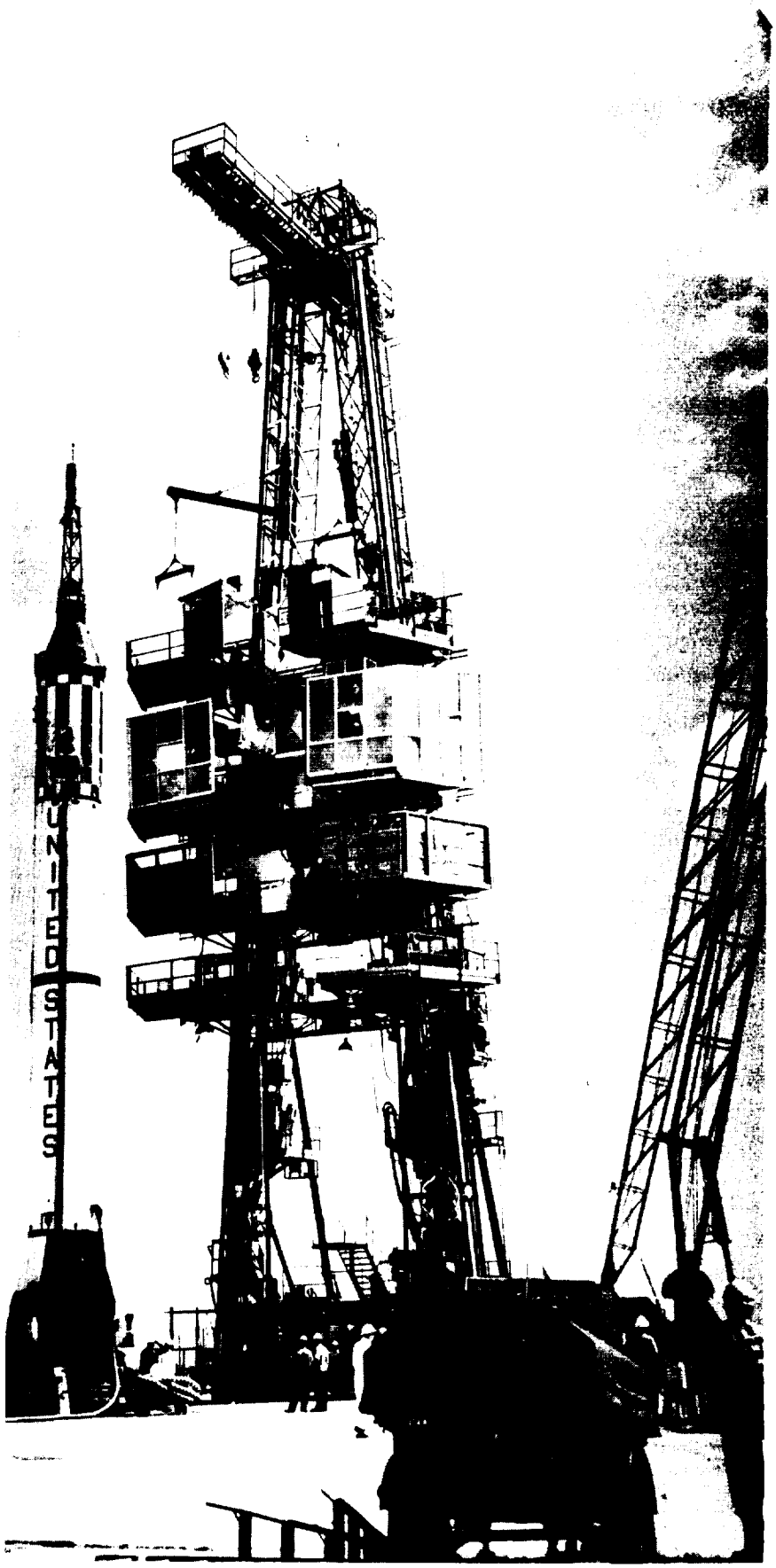



Figure 7-7. Service Structure, Pad 5, VLF 56, Cape Canaveral

- Special hospital-type floor coverings.
- Air conditioning system to provide a 20 percent safety factor for both temperature and humidity control.
- A 20 by 50-inch camera platform with live load capacity of 350 pounds.

Since this project was carried out on a crash basis, it is obvious that no formal design procedures were possible. The enclosure was consequently designed and constructed on a day-by-day basis on the site in order to meet the required date for MR-3. The room proved effective and satisfactory in the flights of MR-3 and MR-4 and is shown in Figure 7-8.

#### 7.5.1.3 Escape Rocket Flame Deflector

A solid fuel escape rocket and tower were attached to the capsule. This rocket was to be used to separate the capsule from the booster if a catastrophic condition had occurred. The presence of this escape rocket above the space vehicle created a hazardous condition which would have proved fatal to personnel on the structure if inadvertent ignition had occurred. No explosive train interrupter (safing and arming device) or exploding bridgewire system was incorporated in the escape rocket. In order to eliminate this potential hazard, LOD requested that a flame and blast deflector be provided. Figure 7-9 shows the design of the service structure.

#### 7.5.1.4 Remote Controls

Remote control of the MERCURY-REDSTONE service structure was initially proposed for the purpose of expediting lengthy countdown periods. The installation and operational approval was completed in August 1960. In subsequent discussions concerning emergency egress on the launch pad, it was decided to utilize the remote control provision for emergency purposes. System modifications were required to meet the exacting demands of emergency operation within existing design limits. Additional requirements involving special television camera installations for remote control purposes, a remote open-close control for use by the astronaut and rescue crew for Platform Three, and a backup power source were added. The remote control panel shown in Figure 7-10 was mounted near the pad safety position in the blockhouse. In addition a remote control for lowering the mobile aerial tower was provided. The remote controlled service structure proved very effective in operations. Adaptation of remote controls to support emergency egress procedures were accomplished on a crash basis during the three months and five days interim between the launches of vehicles MR-2 and MR-3 on a time-available, noninterference basis.



Figure 7-8. White Room on Level 3, Service Structure, VLF 56

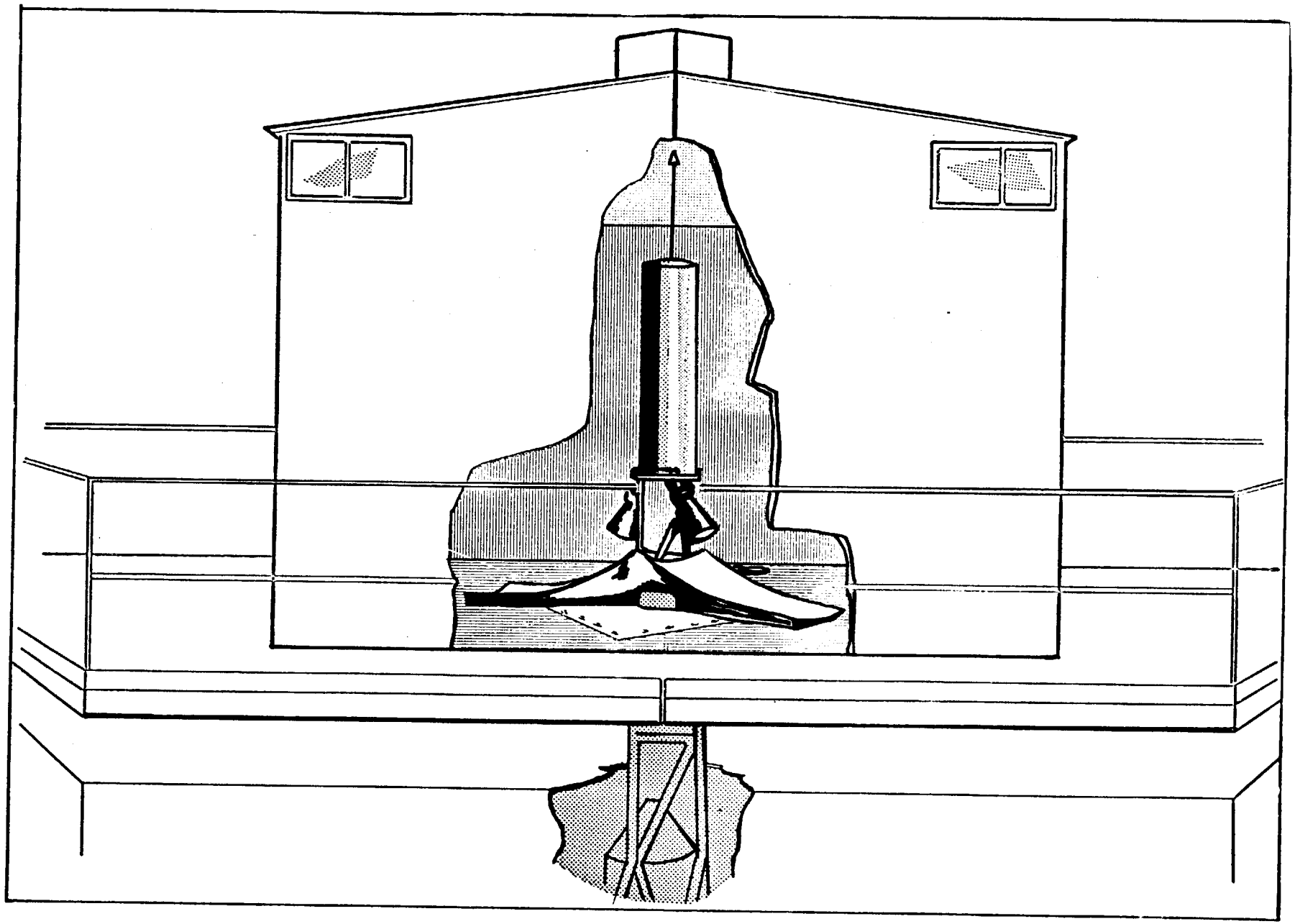


Figure 7-9. Design of Blast Deflector, Service Structure, VLF 56

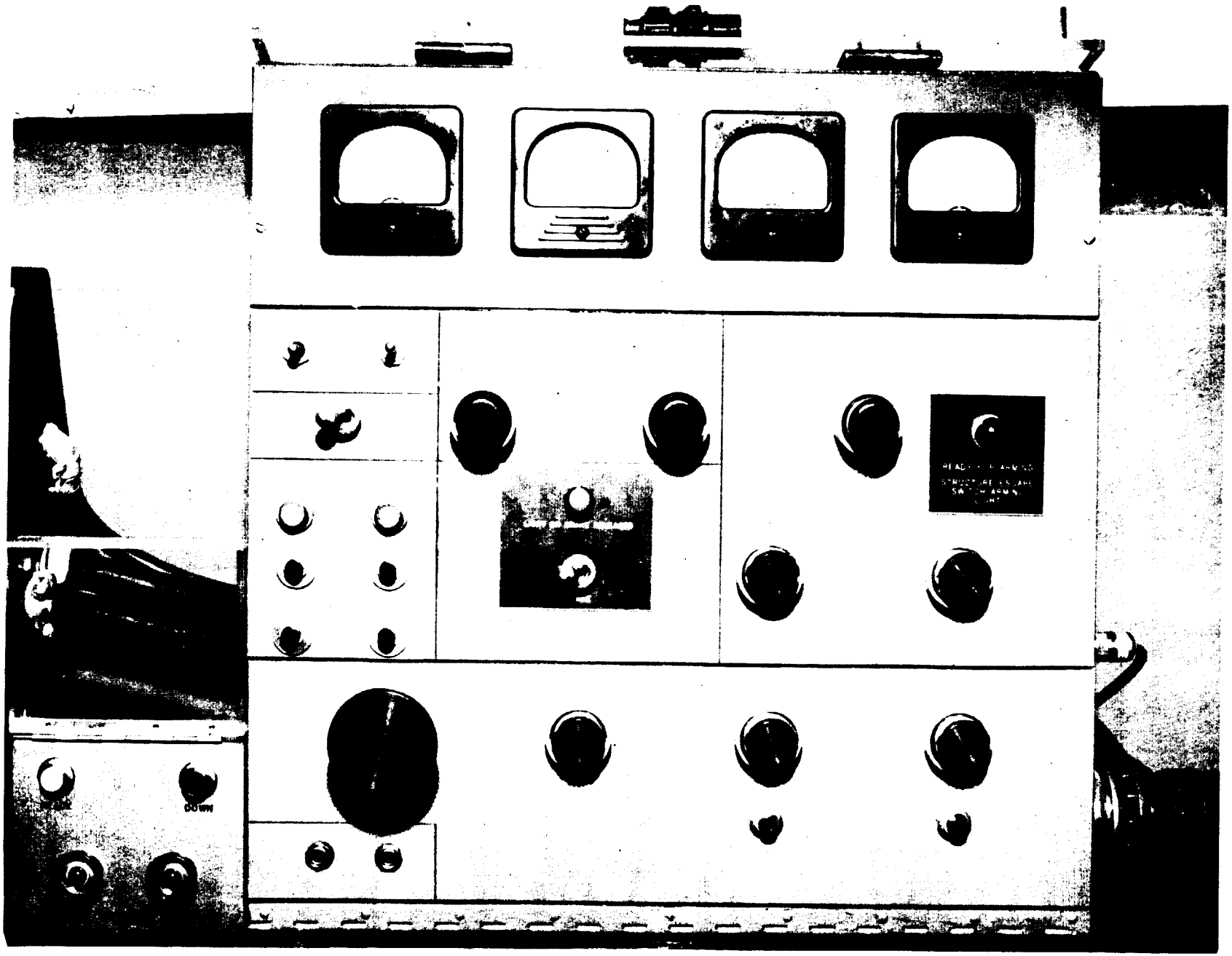


Figure 7-10. Remote Control Panel, Blockhouse 56

#### 7.5.1.5 Television

To provide visual monitoring for remote control by the blockhouse and for information to the MERCURY Control Center, television cameras were mounted in several locations on the structure and around the launch pad area. Two of these cameras were located inside the white room on level three to show capsule operations. The camera located on the northwest side of level three, was mounted so that it could be remotely positioned to look at the MERCURY-REDSTONE vehicle after service structure removal. A third camera was mounted at ground level on the east side of the structure to show service structure movement relative to the launch vehicle. A fourth camera, mounted on top of the blockhouse, presented an over-all view of the launch pad. All of these cameras could be controlled and positioned remotely from within the blockhouse. A fifth camera, positioned to show the DOVAP recorders in the blockhouse, was activated after service structure removal, and was substituted for the number four camera located on top of the blockhouse. The video output of these cameras was also made available to the commercial television networks for use in their nationwide coverage of the manned MR-3 and MR-4 flights at the discretion of the NASA Controller.

#### 7.5.1.6 Auxiliary Platform

It was originally intended that the capsule contractor would provide such necessary scaffolding and access media on levels three and four of the service structure as required. In a meeting on 6 October 1960, of the launch operations committee, STG advised that provisions for access to various levels of the capsule were too restricted and proposed an auxiliary level at the base of the escape tower. This problem was revealed during the first mating of MR-1. An analysis of the problem was made and an auxiliary platform was proposed which would accommodate six personnel and 300 pounds of equipment. The platform would also provide associated electrical interlocks, railings, access ladders, and other equipment. Installation of the platform was satisfactorily completed by 8 December on a priority basis. This platform is shown in the upper section of Figure 7-11.

#### 7.5.1.7 Platform Reinforcement

Platform three was designed for load limits of 10 personnel (2000 pounds) and 500 pounds of equipment. During the first mating of MR-1 at CCMTA, it was observed that these load limits were exceeded and that the platform was being deflected. Investigation revealed that platform loads were approximately 4000 pounds with greater loads to be

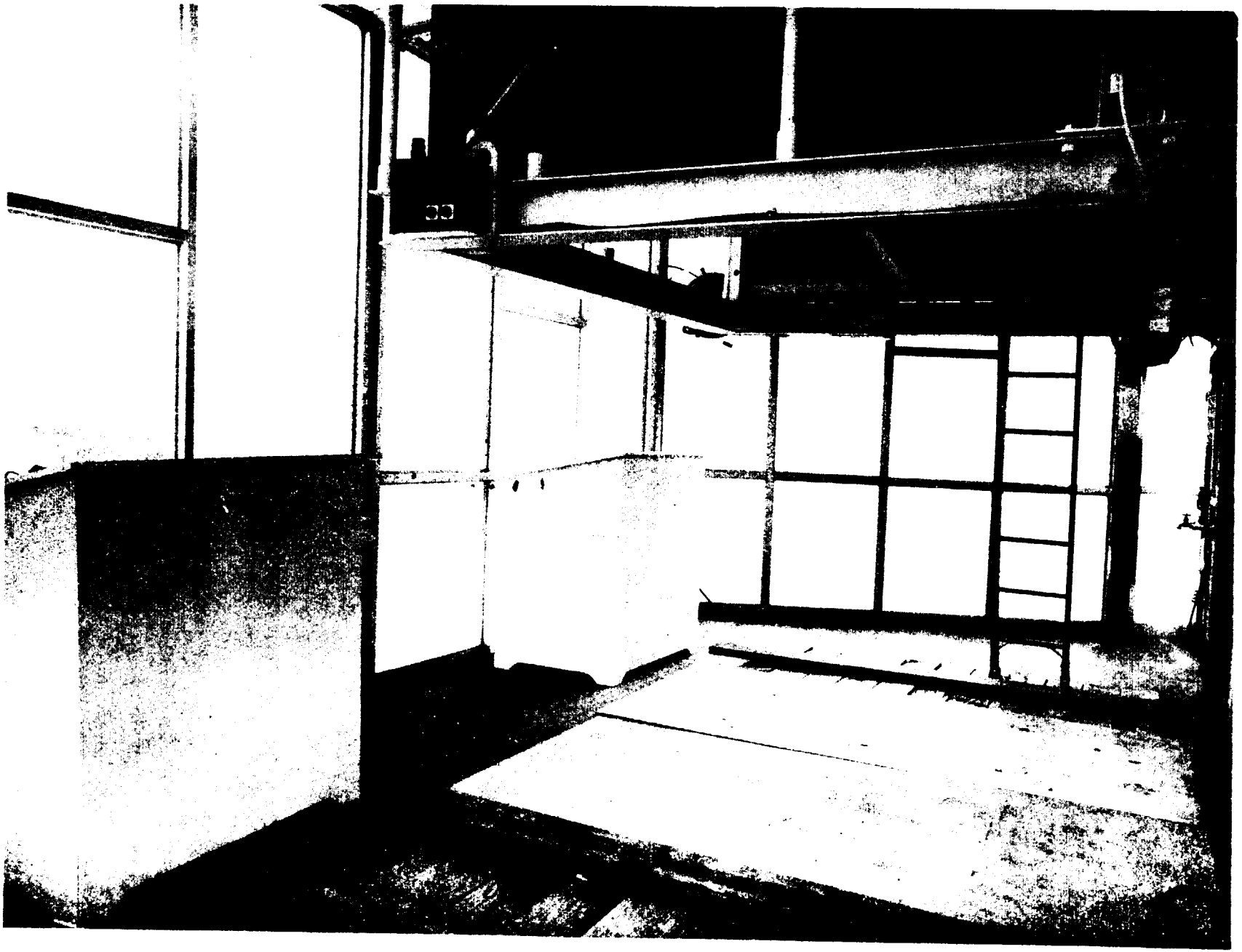


Figure 7-11. Auxiliary Platform, White Room, Service Structure, VLF 56

expected during the manned flights. Design of the reinforcement proceeded at an accelerated pace, and installation on the structure was scheduled between flights of MR-2 and MR-BD on a noninterference basis. The installation was completed in February 1961.

#### 7.5.1.8 Miscellaneous Modification Requirements

A number of additional modifications of lesser magnitude, fulfilled on a priority basis, are as follows:

- A special shelter was provided on the fourth service structure level to provide protection of the capsule from the elements and improve working conditions. This entailed rehabilitation and modification of an available shelter.
- A special enclosed cable storage platform was provided for safe and protected storage of the capsule cables.
- A cable boom was provided on the structure to keep cables, used to connect capsule trailers, off the ground and free from potential damage.
- Additional lights were provided in the shelter house and on the structure level to provide adequate illumination for work and for photographic coverage.
- Special handling equipment for the capsule tester was designed and manufactured.
- Cable trays and cable hanging equipment were designed and installed between levels three and four.

### 7.5.2 GROUND ABORT COMMAND SYSTEM

The mission of the MERCURY-REDSTONE vehicle was such that the circuitry and monitoring panels in the GSE, used for the abort system and booster checkout, required a somewhat different approach from the unmanned missiles. Abort capability, generally, was an integral part of the vehicle systems. The Launch Director could initiate abort by hardwire until liftoff and by radio command until eight seconds after launch. Since the blockhouse had adequate windows from which booster performance could be observed to eight seconds after liftoff, the ground abort command emanated only from the blockhouse during this period. During the subsequent part of the flight, abort command authority was turned over to the MERCURY Control Center.

Redundancy for the abort system required that each hardwire abort line, from the GSE to the vehicle, have the capability to command an abort should the need arise. The MERCURY-REDSTONE vehicle also incorporated a means by which the destruct system could be checked without simulating vehicle liftoff. This was accomplished by adding circuitry and components to the GSE to provide a liftoff signal to the command receivers only.

Abort batteries were incorporated into the ground support equipment to maintain an abort capability by the Launch Director in the event of a launch complex power failure. This was accomplished with relays which would normally be energized but which would de-energize with the loss of power and place the capabilities of receiving abort indications, sounding a buzzer, and retaining the indications when received. This provided a reliable and effective means to monitor, detect, and correct malfunctions and/or improper operation of the abort system.

After liftoff, telemetry data, optional from two ground stations, was transmitted (one via hardwire) to the brush recorder, which was maintained in the firing room to monitor the control and abort systems, tilt program, and premature cutoff. This information was provided to the RF abort panel operator so that RF abort capability would be monitored after liftoff. Shutdown of the engine in normal flight was accomplished by an integrator cutoff which differed from most other launch vehicles. An integrator clock panel was used in the GSE to check the integrator time. Engine combustion pressure switches were incorporated as a part of the automatic abort system to sense a loss of combustion pressure. Two methods were designed into the GSE to check the reliability and operation of the switches. First, a pressure simulator near the combustion chamber was used to check the pneumatic operation, and secondly, relays were utilized to check the circuit electrically.

A followup ground cable was added to insure that the ground potential of the vehicle remained the same as the ground potential of the GSE. During the initial investigation of the GSE, it was discovered that the Tempo relay timers being used were not reliable. These were replaced with Agastat timers. As a general rule, the masts and umbilical plugs of the launch vehicles were ejected pneumatically. In the case of this vehicle, the capsule umbilical plug was equipped with an electrical release backed up by a mechanical release. The electrical release caused some concern because of its failure to function properly during several preflight tests and on at least one occasion during a launch. However, since the mechanical release was proved to be reliable, no action was taken to correct the fault in the electrical release.

## 7.5.3 BLOCKHOUSE ELECTRICAL GROUND SUPPORT EQUIPMENT

### 7.5.3.1 General

The following specialized equipment, required for the launching of MERCURY-REDSTONE vehicles, was installed in the blockhouse on Vertical Launch Facility (VLF) 56.

### 7.5.3.2 Inverter Panel

The inverter panel, shown in Figure 7-12, was a standard inverter panel used for previous vehicles. It presented frequency deviations and voltage indications and contained controls for the ground and vehicle 115-volt, 400-cycle inverters.

### 7.5.3.3 Environmental Control Panel

The environmental control panel, shown in Figure 7-13, was used to control and monitor the launch vehicle instrument compartment cooling system. In addition, the instrument compartment could be pressurized by a manual control located on this panel.

### 7.5.3.4 Measuring Panel

The measuring panel, shown in Figure 7-13, provided control of all RF equipment onboard the vehicle which consisted of the telemeter, DOVAP, AZUSA, and television systems. An RF silence switch was installed in series with these controls to prevent the equipment from radiating during periods of RF silence.

In addition, the panel had a 5-volt measuring supply indicator with a switch to monitor either the ground or vehicle power supply, command receivers, control and function indicators, a control for arming the destruct package, miscellaneous switches to simulate DCR liftoff, thrust sensing line heater control, control voltage sensor abort blocking switch, and booster abort blocking switch. The thrust sensing line heater switch was a manual control used to turn the heaters on prior to power transfer. The block booster abort switches were used to prevent the capsule from receiving an abort signal from the booster during booster checkout.

### 7.5.3.5 Auxiliary Propulsion Panel

In addition to a test power switch, the auxiliary propulsion panel, shown in Figure 7-14, included the components test, instrument compartment pressure test, and the ac heater control. The test power switch provided power for the components test and

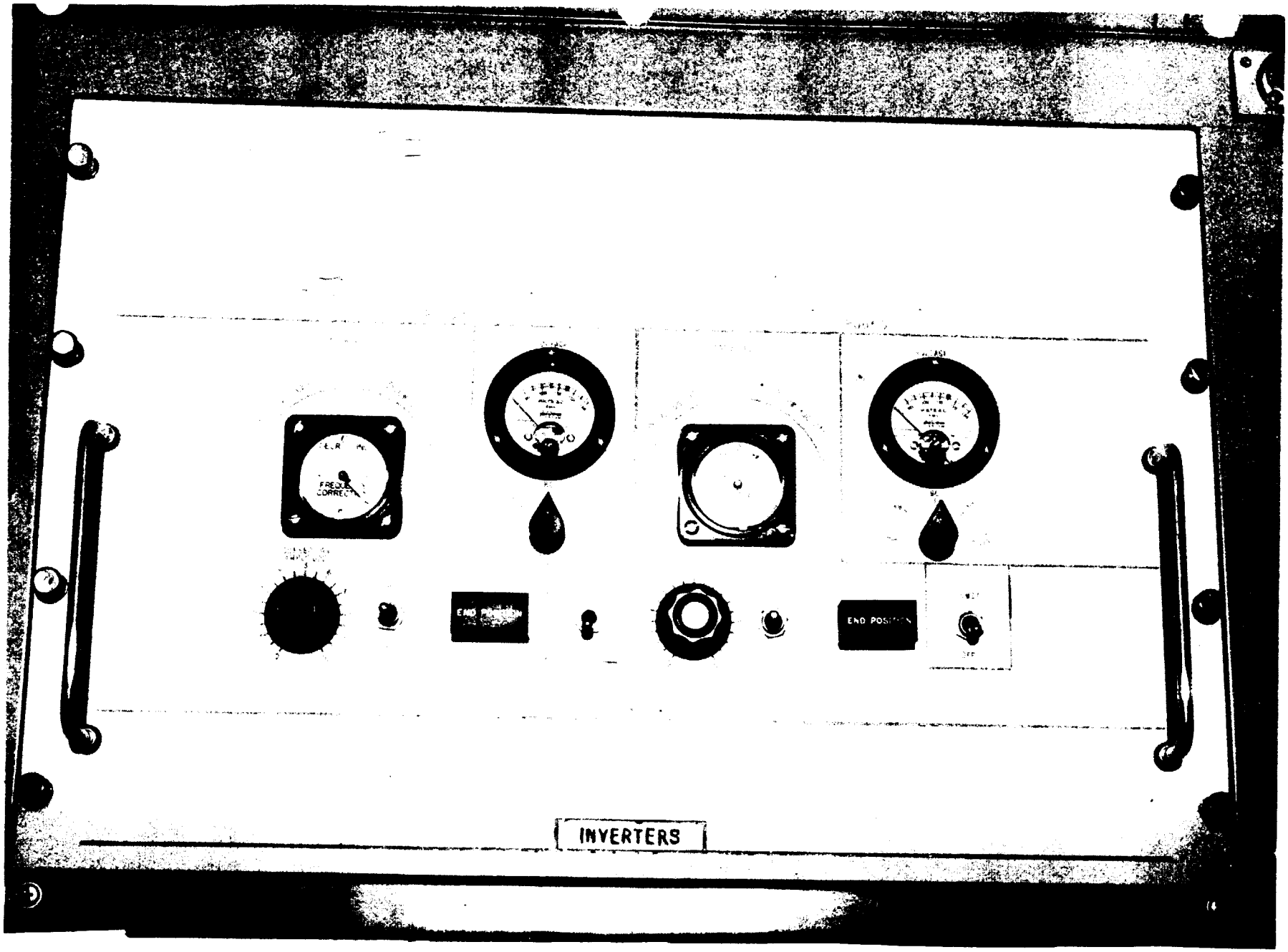



Figure 7-12. Inverter Panel, Blockhouse 56

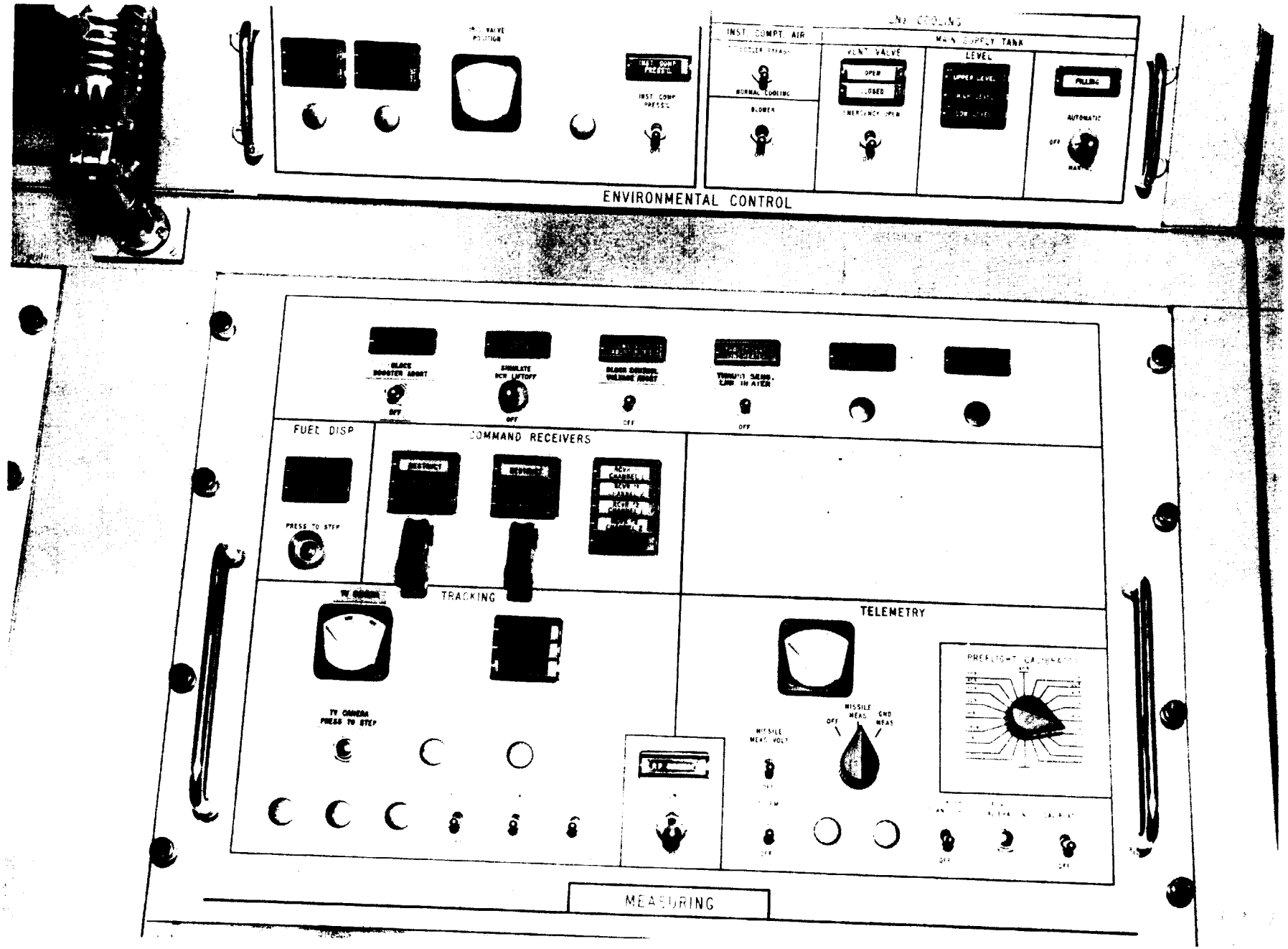



Figure 7-13. Environmental Control Panel and Measuring Panel, Blockhouse 56

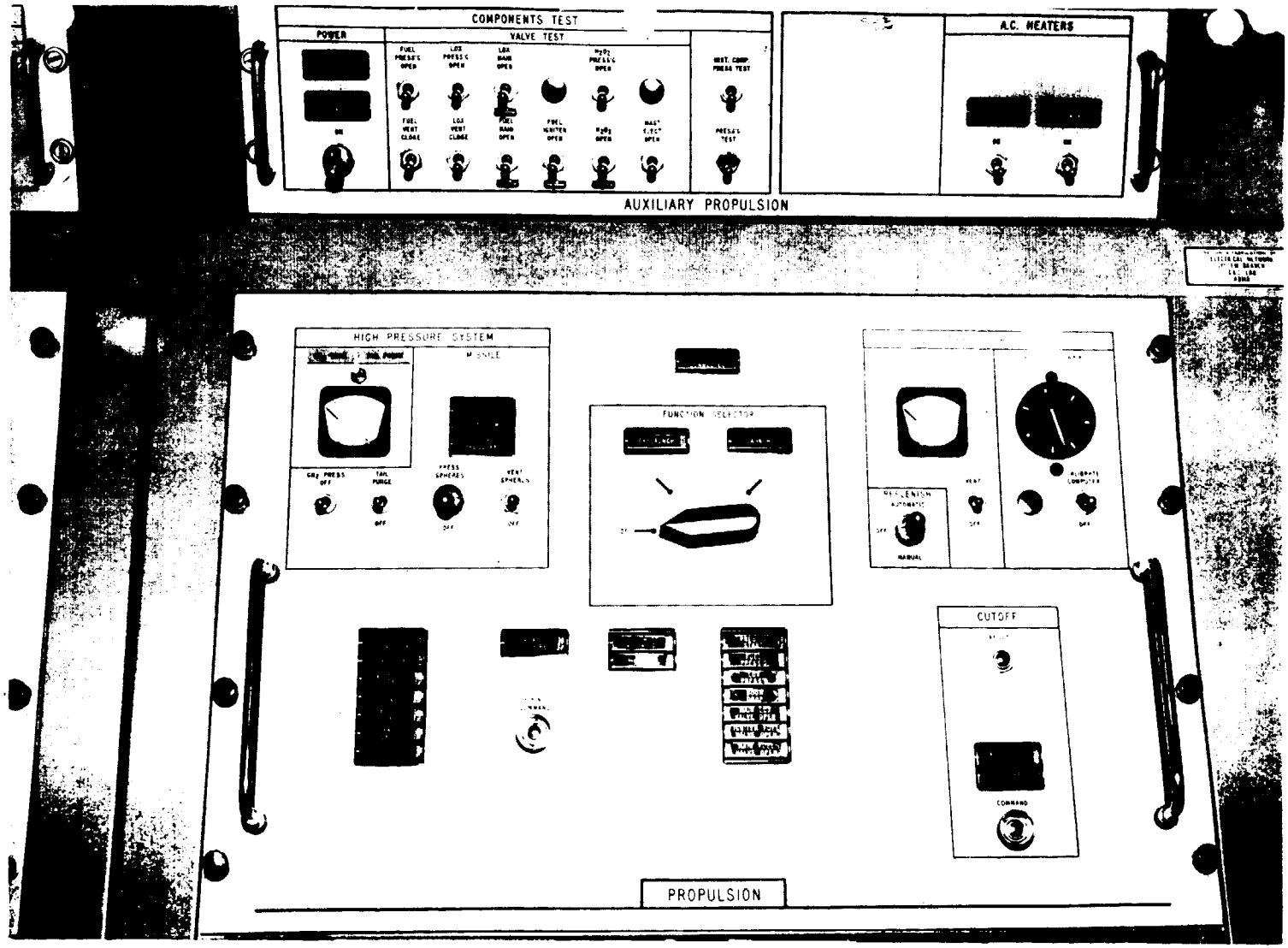



Figure 7-14. Propulsion and Auxiliary Propulsion Panels, Blockhouse 56

instrument compartment test portions of the panel. This switch was de-energized when the function selector switch was positioned in the launch position. The components test switches provided manual control for individually operating all the main valves in the propulsion system. The instrument compartment pressure test switch was provided to manually pressure test the compartment. The 115-volt, 60-cycle LOX valve and the hydrogen peroxide ($H_2O_2$) equipment heaters were also controlled from this panel.

#### 7.5.3.6 Propulsion Panel

The propulsion panel, shown in Figure 7-14, was the standard model as used in previous REDSTONE missile launchings and contained a function selector switch, cutoff command and cutoff reset control, firing command button, high pressure system indications and controls, and the LOX replenish system indications and controls. In addition to the ready-to-fire and automatic sequence chains, the panel also presented the abort bus hot indication.

#### 7.5.3.7 Over-all Test Panel

The over-all test panel, shown in Figure 7-15, was previously used as a portable console set up at the tail of the booster and removed after each test. For the MERCURY-REDSTONE Program, it was made a permanent item of GSE. The panel contained control switches for all the simulations of the vehicle during an over-all test, including: tank pressurization, boom drop, ignition, mainstage, liftoff, and combustion pressure switches 1 and 2.

#### 7.5.3.8 Auxiliary Network Panel

The auxiliary network panel, shown in Figure 7-16, monitored and controlled specific MERCURY-REDSTONE functions. The panel contained the power transfer test switch and the emergency missile power-Off button. The sequence recorder control, cutoff indication light with a cutoff buzzer and arming switch, a voltmeter with a selector switch to monitor the abort batteries (when the abort battery switch was On), voltmeters to monitor the D104 and D105 ground busses, and indicator lights for signifying potential faults in the ground and vehicle inverters were also contained in this panel.

#### 7.5.3.9 Generator Panel

The generator panel, shown in Figure 7-16, was the standard type used on all previous missiles. It provided a constant 28 volts for ground and vehicle power until the vehicle

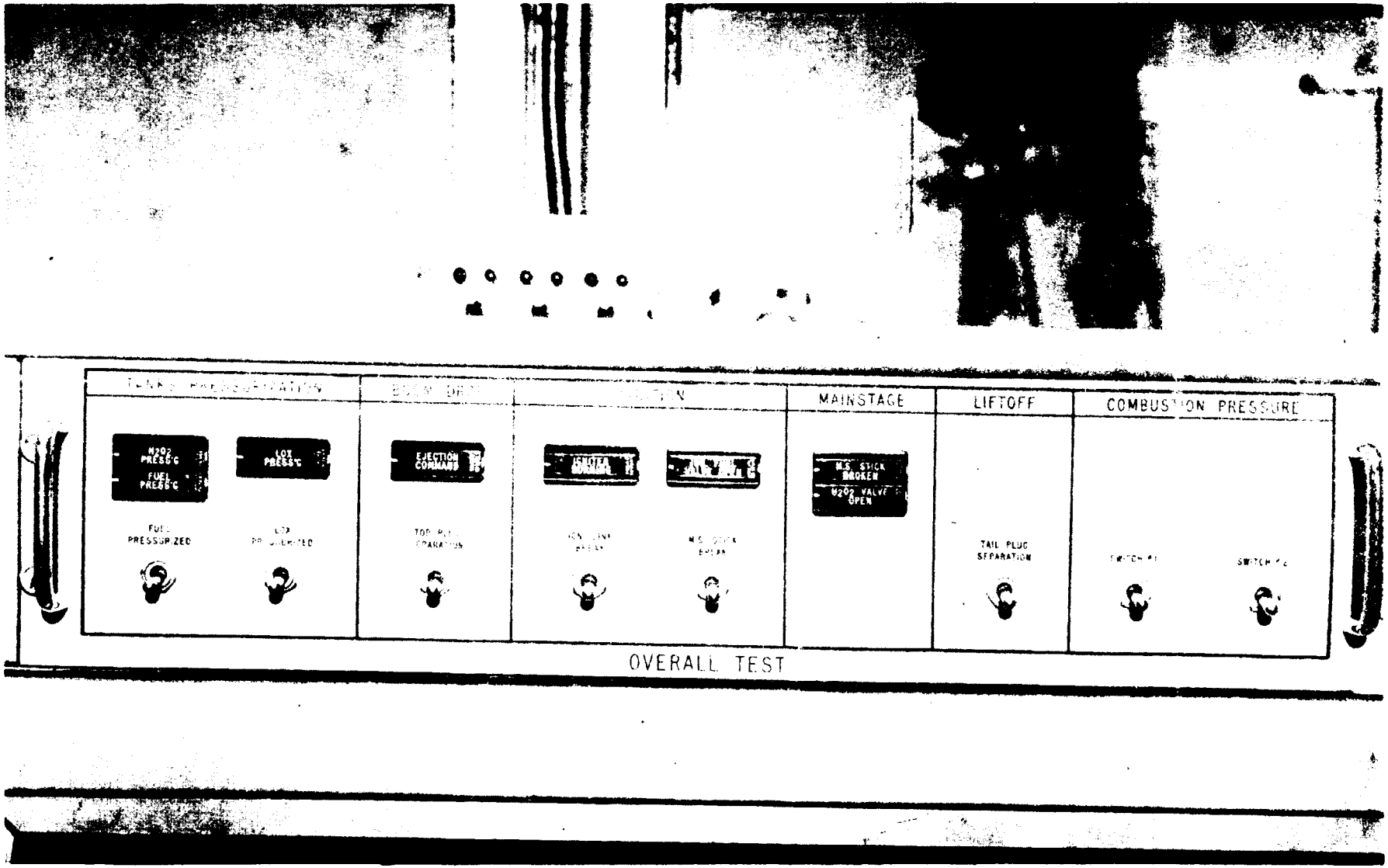



Figure 7-15. Over-all Test Panel, Blockhouse 56

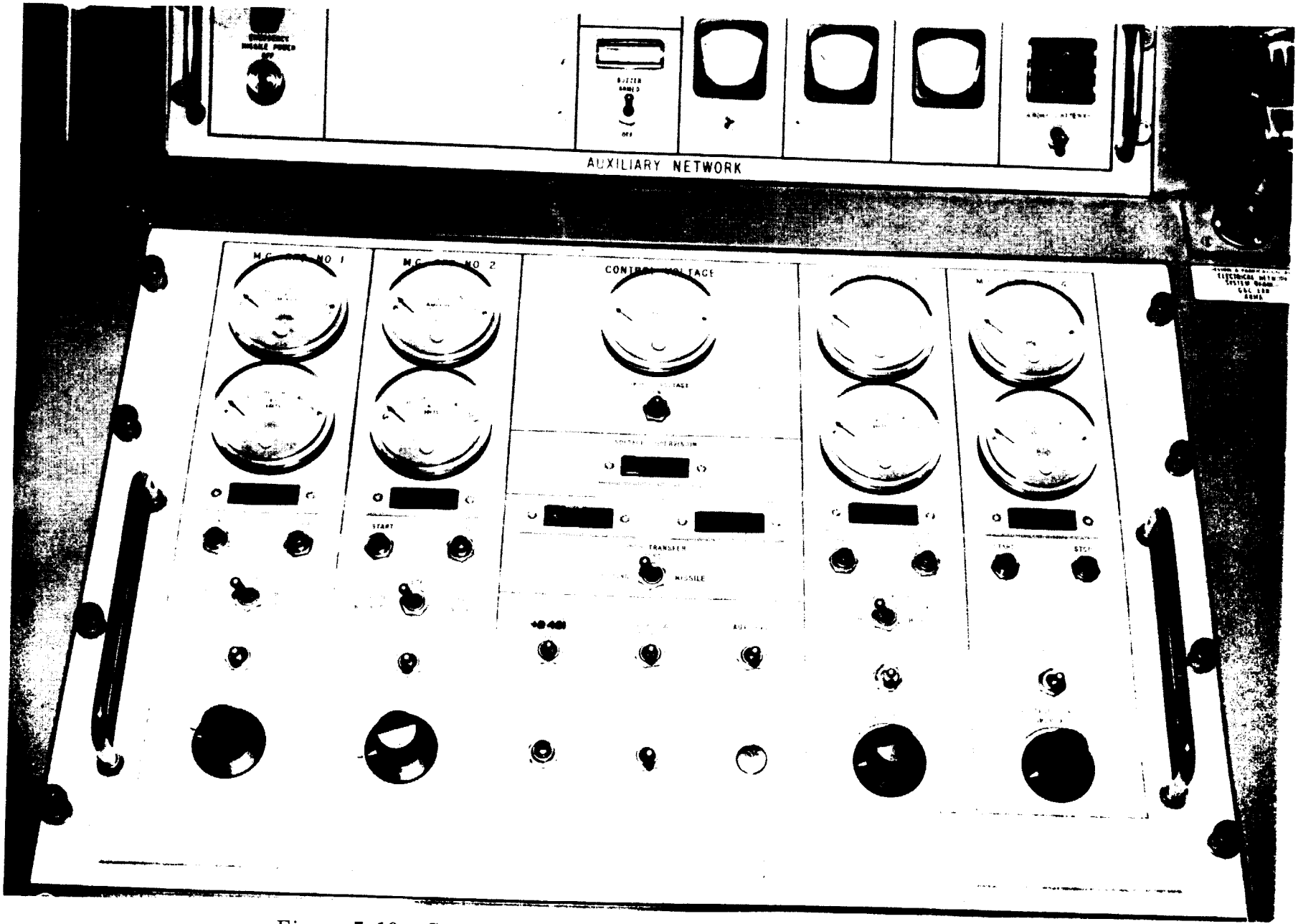



Figure 7-16. Generator and Auxiliary Network Panels, Blockhouse 56

was switched to internal power. Generators 1 and 2 provided voltages for the vehicle and associated ground equipment. Generator 3 provided 28 volts to the capsule monitor rack in the blockhouse and utility room. Generator 4 provided 28 volts for miscellaneous ground support not directly connected with the vehicle. The panel contained a voltage supervision indicator as well as ground and vehicle power indicators.

#### 7.5.3.10 Autopilot Rack

The autopilot rack, shown in Figure 7-17, was composed of the control panel, autopilot (LEV-3) panel, and the integrator timer panel. In addition to monitoring the vane positions utilized for vehicle attitude control, the control panel provided the controls for the control computer, flight sequencer, and the program device, the LEV-3 control, and monitors for the gyro output.

Associated with the autopilot rack was a brush recorder that monitored the input of the control computer and the position of vanes II and IV. These signals were monitored only until liftoff.

#### 7.5.3.11 Test Conductor's Console

The test conductor's console, shown in Figure 7-18, was made up of three panels consisting of the vehicle status and abort panel, countdown clock master control panel, and the communications panel. The master clock panel provided launch vehicle countdown and control by the launch test conductor. The communications panel gave the test conductor the ability to communicate with all blockhouse stations (except the black phone), the supervisor of range operations, and a range countdown speaker. The vehicle status panel at the left gives the status of critical functions determined essential for conduct of the countdown. Abort indications are given by lights and buzzer. Indications thus received are retained until positive action is taken.

### 7.5.4 COMMUNICATIONS

In addition to the usual communications used in all missile launches, the following special communications links peculiar to the MERCURY-REDSTONE manned flights, were utilized:

- Voice Communications with the Capsule
  a. UHF radio link.
  b. VHF radio link.
  c. MOPIS (Missile Operational Interphone System) (prior to liftoff).

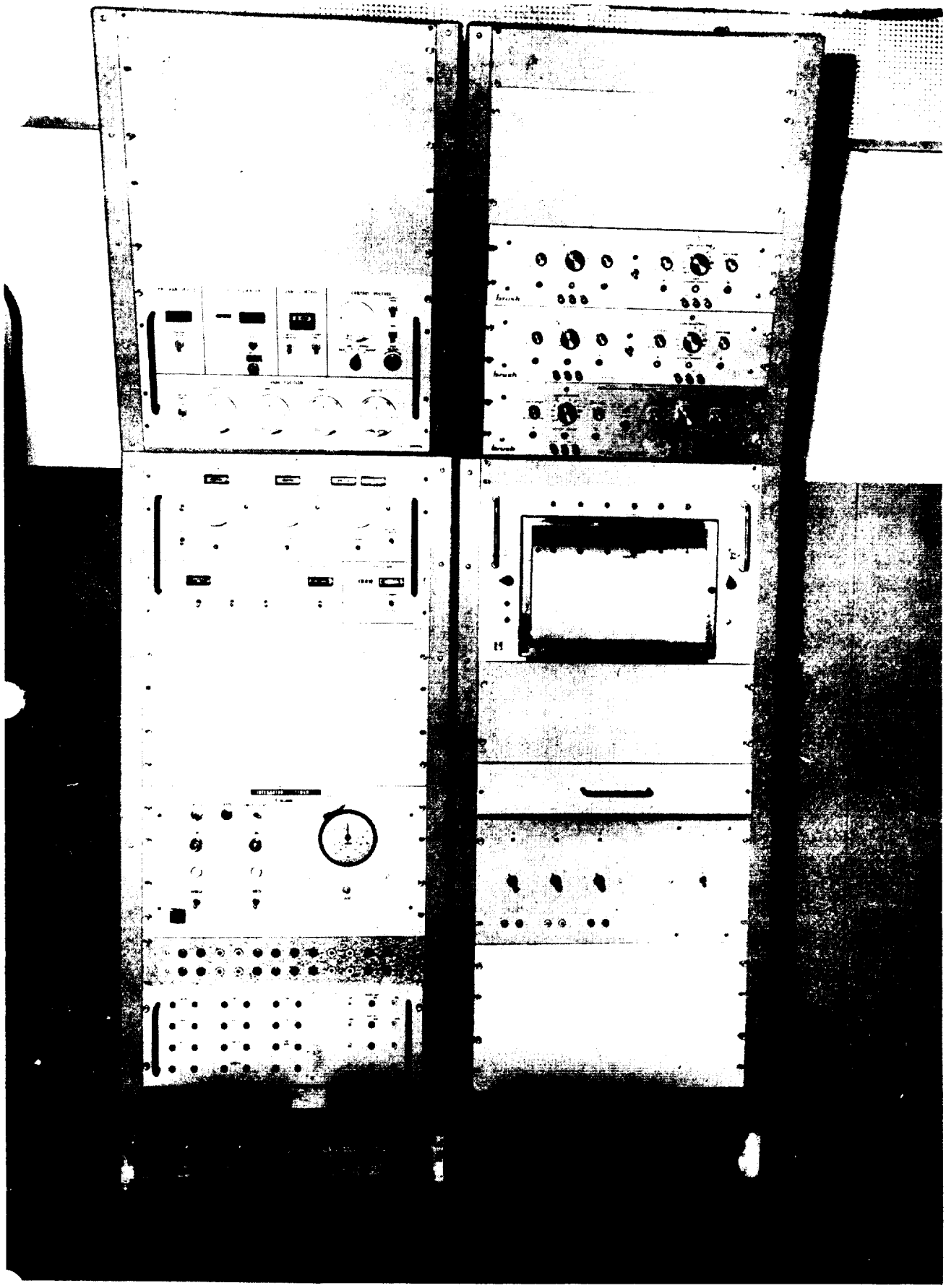


Figure 7-17. Autopilot Rack, Blockhouse 56

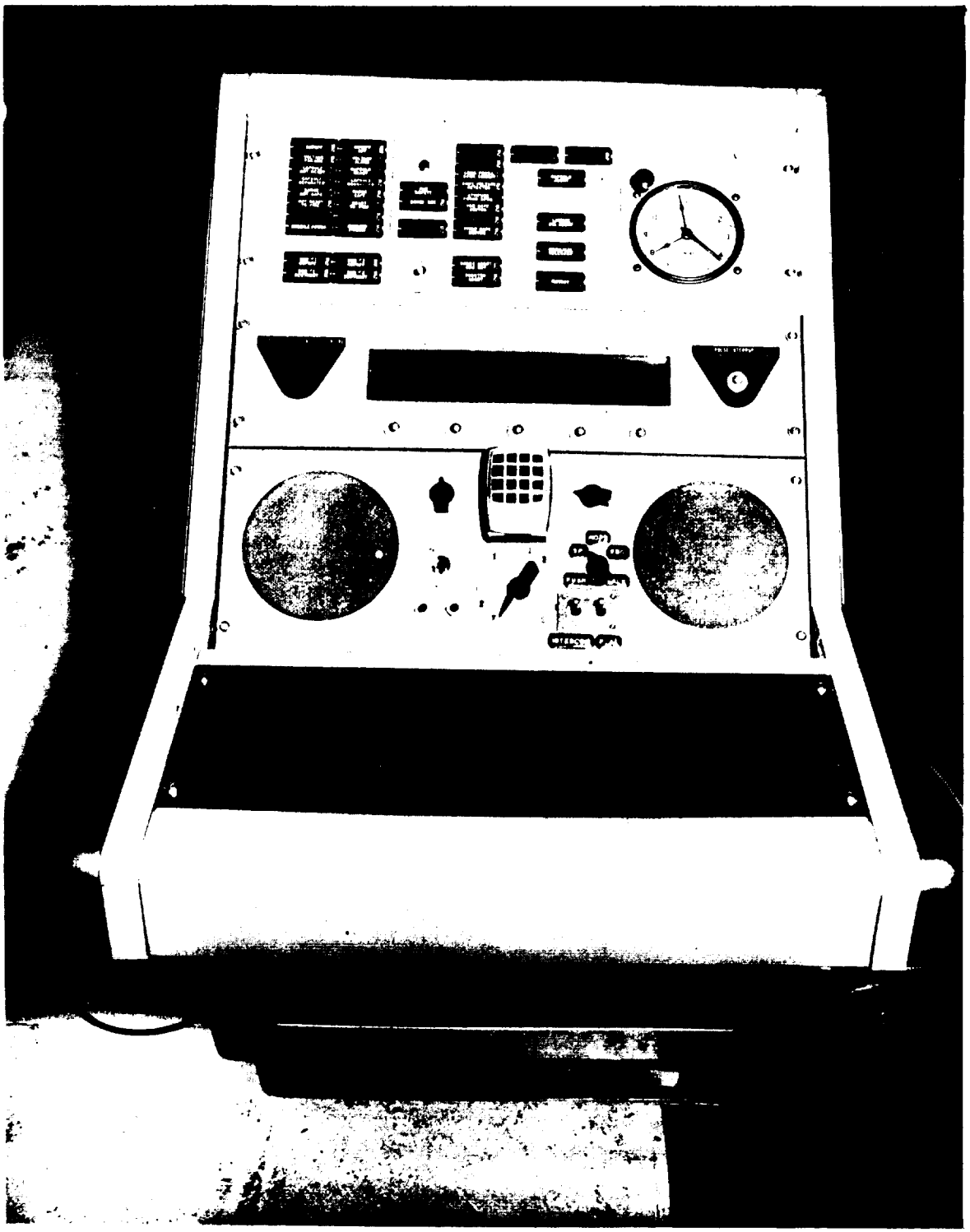


Figure 7-18. Test Conductor's Console, Blockhouse 56

- High frequency radio network for recovery and rescue operations operating on 30.3 mc.

Figures 7-19 and 7-20 show graphically the many participating individuals and agencies who had either a monitor or transmit-receive capability on one or more of these special communication links in support of launch operations.

A short time preceding the launch of MR-3, a NASA policy was established which permitted on-the-spot transmission of launch operations to the public. This required a crash program to provide this coverage and to organize operations so as not to interfere with the preflight procedures. To minimize interference with critical operations, it was decided to exclude live television from the blockhouse and MERCURY Control Center. In order to maintain security, the networks were required to provide one camera crew from a television pool, and a single mobile unit which was present until final service structure removal. One television camera was installed on level three and wired through Blockhouse 56 for use by the news media. Four television pictures were provided by the launch operations directorate from their closed-loop system used in support of operations. These five television channels were controlled by an LOD operator in Blockhouse 56. Television coverage thus provided was transmitted to Blockhouse 26 through cables provided by the news media. The command station at Blockhouse 26 was manned and monitored by commercial networks personnel. The mobile unit had the capability of direct broadcasting. A 208-volt power source was made available to the mobile unit from the Cape operational critical power. This mobile unit was located between Complexes 56 and 26 during the periods when access was permitted to the complex. This arrangement proved satisfactory and was repeated to a somewhat lesser degree during the launch of MR-4.

An informational telephone network was set up for each operation. A three-point operational telephone link was provided between the blockhouse, MSFC, and the Advisor to the Office of Launch Vehicle Programs at NASA Headquarters. An additional commentator link from the information center in Hangar R relayed information to Washington, MSFC, and local points, such as the press site. In addition, a commentator link was provided from the observation room of the MERCURY Control Center to the Office of Space Flight Programs at NASA Headquarters, Washington, D.C.

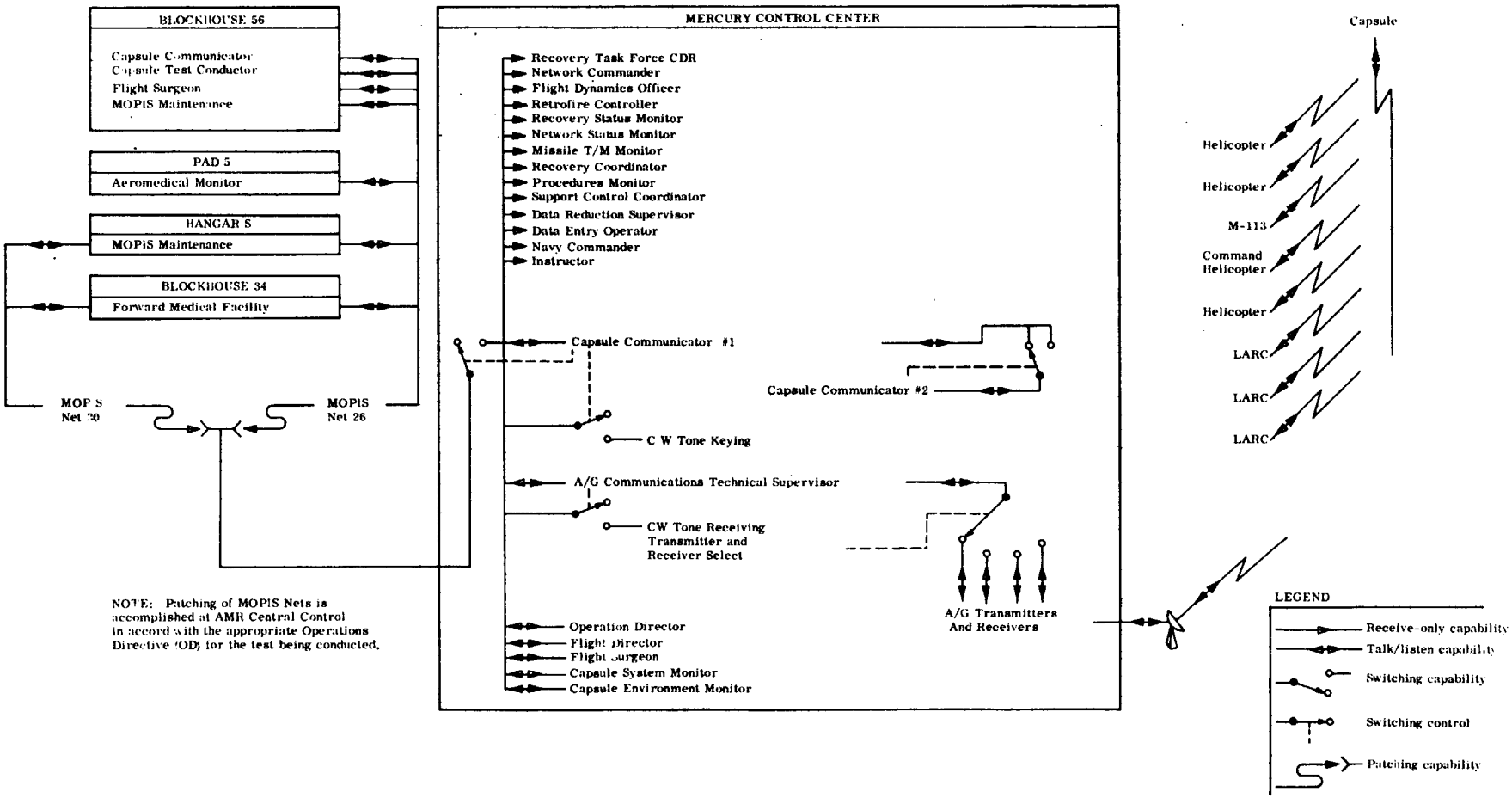



Figure 7-19. Capsule Radio Network - UHF

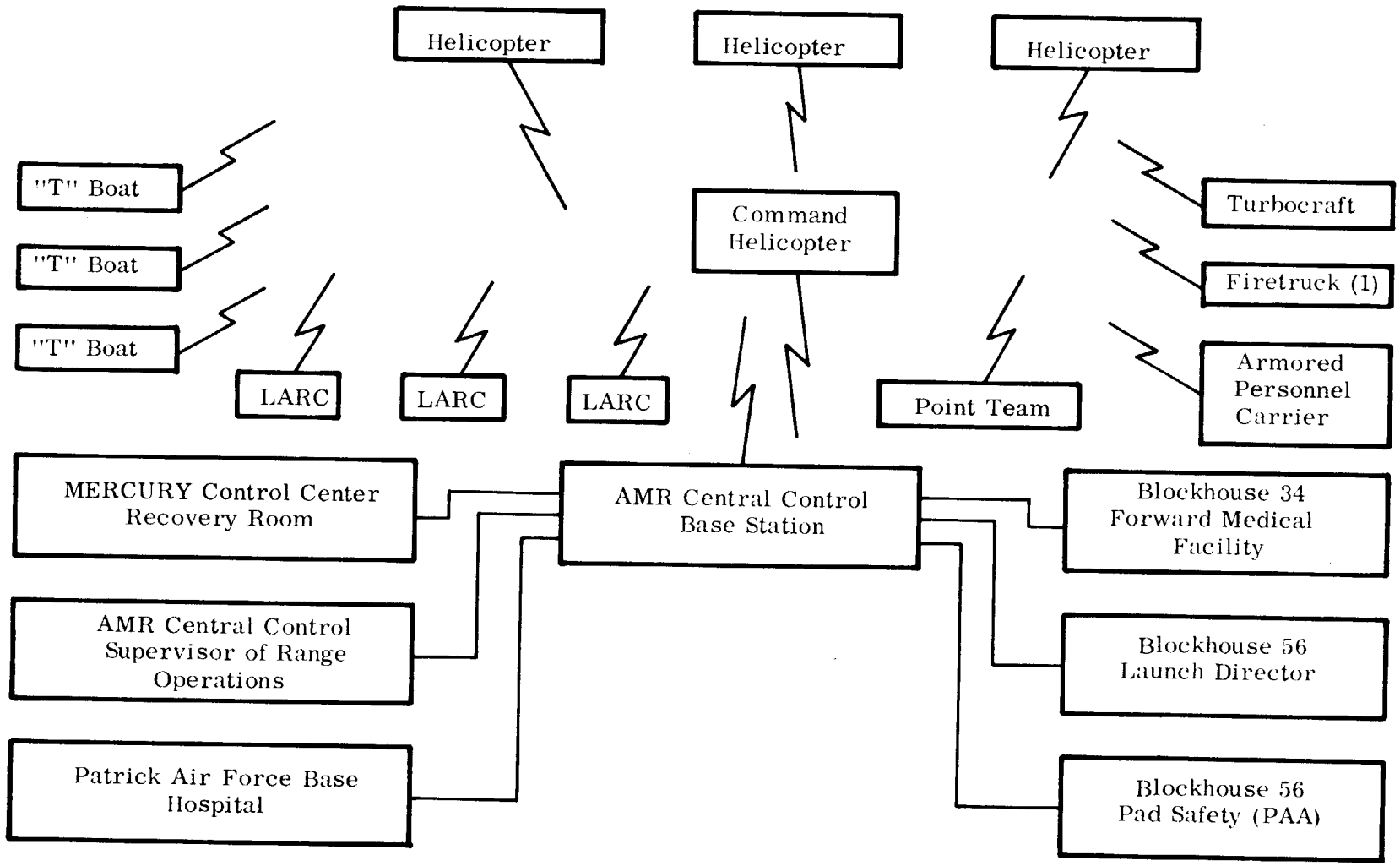



Figure 7-20. Recovery and Rescue Radio Network, High Frequency 30.3

## 7.5.5 INSTRUMENTATION

### 7.5.5.1 Monitoring Instrumentation

Instrumentation used at AMR for monitoring the launch of rockets was divided into four categories. These consisted of metric tracking instrumentation, engineering sequential and documentary photography, telemetry equipment, and flight safety equipment. For the MERCURY-REDSTONE flights another category was added which could be called "communications and recovery instrumentation." Much of this instrumentation fell into more than one category. Metric tracking data was required to evaluate the vehicle guidance and control performance, power plant performance, and aerodynamic effects. Photographic coverage was required to obtain a visual record of flight events. Telemetry was the primary means for obtaining data of onboard functions. Vibrations, strain measurements, guidance computer inputs and outputs, platform positions, gas turbine speed, combustion chamber pressure, and single events such as separations, retrorocket ignition, and parachute deployment, are samples of the type data obtained from telemetry. Flight safety instrumentation was used by RSO to monitor the vehicle during flight. Vehicle velocity, position, real-time impact point, and television monitors were displayed in central control for the RSO.

### 7.5.5.2 Metric Instrumentation

Metric instrumentation was broken down into two categories: electronic instrumentation and optical instrumentation.

- Metric electronic instrumentation consisted of the following:

  a. C-band radars at Cape Canaveral, Patrick AFB, Grand Bahama Island (GBI), Carter Cay, and San Salvador tracked the C-band beacons in the MERCURY capsules. The ground stations, except Carter Cay, beacon tracked to loss of signal. Carter Cay tracked on passive beacon track and skin track. Uprange and GBI radars were available as tracking sources for the impact predictor. In addition to furnishing vehicle position and its derivatives, video cameras were operated on the phasing scopes to record the separation distance between the capsule and the booster. The C-band radar accuracies for MERCURY-REDSTONE varied from 0.6 to 91 meters from T+10 seconds to almost impact.

  b. S-band Mod II radars located at Cape Canaveral, GBI, and San Salvador (AMR sites) and the S-band VERLORT (very long range

tracking) radar at Bermuda (NASA site) tracked the S-band beacons of the MERCURY capsules. The AMR S-band radars were operated as backup for the C-band radar, with the data to be reduced only if the C-band radar data were not sufficient. The quality of C-band data obtained in the MERCURY-REDSTONE program was such that S-band data reduction was not required.

c. DOVAP (Doppler velocity and position) stations at Blockhouse 56, Hangar D, Lateral Site B, Program Site C, Merritt Island Airport, Titusville-Cocoa Airport, and Playalinda Beach, tracked the booster DOVAP transponders on a frequency of 73.738 mc. Transmitter site 1.3.4 on the Cape interrogated the beacon and provided a reference signal for the receiver stations. The accuracies of velocity and position data obtained, ranged from 0.1 meters per second to 1.7 meters per second and from 0.05 meter to 23 meters respectively, for powered flight. DOVAP was removed from the MR-1 and MR-1A flights, because the combined DOVAP transponder and a capsule telemetry transmitter blocked out the onboard command receiver. The telemetry frequency was changed on subsequent vehicles.

d. AZUSA Mark I and AZUSA Mark II were both utilized in the MERCURY-REDSTONE Program. Mark I was used for MR-1, MR-1A, and MR-2 flights, and Mark II was used for the MR-BD, MR-3, and MR-4 flights. The booster transponder was interrogated on 5000 mc and transmitted on 5060 ms. AZUSA data were used for the input to the impact predictor for flight safety presentation and also post flight metric data from approximately 20 seconds of flight through separation. Position accuracies varied from 0.03 to 5.8 meters for the same period.

- Metric optic instrumentation consisted of the following:

  a. Fifteen fixed ribbon frame cameras, known as CZR's and RF-5's, were used as the primary metric data source from liftoff to 2000 feet. These cameras with 7- to 20-inch focal length lenses and variable frame format, operated with continuous running film using a synchronized system. The cameras were fixed in orientation, that is, they were not tracking cameras. The azimuth and elevation of the vehicle was determined by referencing the vehicle

light source, paint pattern and/or the base of the flame to fixed reference targets in the field of view of each camera. Position errors varied from 0.04 to 0.1 meter for MERCURY-REDSTONE.

b. Cine-theodolites with 24-inch focal length lenses and 35mm film size, tracked the vehicles from four sites on the Cape, Cocoa Beach, and Patrick AFB. The cine-theodolites photographed the vehicle, azimuth and elevation dials, timing pulses, and the frame count on each picture. This furnished backup data from liftoff to 2000 feet for the fixed ribbon frame cameras and primary data to approximately 150,000 feet altitude. Position accuracies varied from 1.2 to 2.9 meters.

c. Three attitude cameras, using 35mm film and lenses of 40-, 48-, and 60-inch focal length, tracked the vehicles to loss of view. Attitude data (pitch, yaw, and roll) were reduced from 0 to 2000 feet altitude. Yaw and pitch accuracies varied from 0.0 to 0.3 degrees.

#### 7.5.5.3 Photographic Coverage

Photographic coverage was divided into engineering sequential and documentary camera coverage. Engineering-sequential cameras had range timing or a known frame rate, used to correlate visual observations to other data, while documentary cameras did not have range timing. The metric cameras naturally provide engineering sequential and documentary coverage, and engineering-sequential cameras also provided documentary coverage. Twenty fixed engineering-sequential cameras, running from 20 to 400 frames per second (fps), were operated in the vicinity of the launch pad. These cameras recorded specific details of the launch phase, varying from flame effects on the launcher to coverage of capsule umbilical plug ejection, and periscope retraction. Thirteen tracking engineering-sequential cameras were in operation on the Cape. Twelve 16mm cameras were running at 96 fps and one 35mm camera was running at 32 fps. These cameras provided general surveillance to loss of view from each camera. Long focal length cameras known as ROTI's (Recording Optical Tracking Instrument) and IGOR's (Intercept Ground Optical Recorder) were also used. ROTI's were operated at Melbourne Beach and Vero Beach using 20 fps and 30 fps, respectively and 500-inch focal length lenses. IGOR's were operated at False Cape (north of Cape Canaveral), Williams Point (north of Cocoa, Cocoa Beach, and Patrick AFB. Cocoa Beach and Patrick AFB operated at 30 fps with 360-inch focal length lenses, False Cape and Williams Point operated at 20 fps with 500-inch lenses.

### 7.5.5.4 Telemetry Links

Two telemetry links were carried on each MERCURY capsule with the same information transmitted on both links for redundancy. The REDSTONE boosters each had one link. These three links were recorded at Hangar D, Blockhouse 56, Cape TEL II, Cape TEL III, GBI, on one or two aircraft, and on one ORV (Ocean Range Vessel). Real-time displays of capsule data were made at MCC, using TEL III data, and a limited number were made at Blockhouse 56 and Hangar D.

### 7.5.5.5 System Displays

During original planning the STG requested that a booster performance and abort system display be provided in the MERCURY flight monitoring trailer. In the absence of firm information on the location and source of telemetry, and because of the limited space available in the flight monitoring trailer, this requirement was subsequently removed. In the interim, program slippage was such that the flight monitoring trailer was eliminated and the TEL III was used to monitor MERCURY-REDSTONE flights.

As a consequence, the STG re-established the request that this information be available within 5 or 10 seconds of demand to the Operation and Flight Director at the MCC to be monitored by a knowledgable MSFC representative. As a result of this requirement, operating ground rules and measuring programs for the manned flights were established as explained in the following:

- The brush recorder displays utilized to monitor the abort system during the open-loop flights were expanded to monitor the manned flights. The abort switches under the left recorder were available to give a backup RF abort command after the first eight seconds by order from the MCC, and during the first eight seconds by request of the Launch Director as a backup to the abort switches. An additional special provision was included in this booster performance display that latched the abort bus signal in the On position in the event an abort signal was generated. Manual operation was required to either turn it off or verify. The input to the booster performance display was alternatively selected from two sources for complete coverage and reliability: (1) blockhouse telemetry receivers, and (2) the TEL II station telemetry receivers for the latter part of the flight. A direct telephone line was provided between the blockhouse booster performance display and the booster console at the MCC to assure immediate and positive exchange of information if an unexpected difficulty occurred during powered flight.

- The blockhouse booster performance display provided 12 channels of information on a brush recorder which was intended to reflect over-all booster performance, and not merely abort system functions. The following measurements were displayed:
  a. Gyro pitch position minus program.
  b. Gyro yaw position.
  c. Gyro roll position.
  d. Deflection jet vane No. 2.
  e. Pressure combustion chamber.
  f. Combustion pressure cutoff switch No. 1.
  g. Abort bus signal.
  h. Attitude error, abort.
  i. Angular velocity, abort, pitch.
  j. Angular velocity, abort, yaw.
  k. Combustion pressure cutoff switch No. 2.
  l. Control voltage abort.
  m. Abort from capsule.
  n. Capsule separation signal.
  o. Emergency cutoff.
- An additional booster performance display was presented on an 8-channel recorder at the MCC for information purposes. The displayed information was transmitted by hardwire from the TEL II station receivers, discriminators, and decommutators to the MCC. There were no telemetry receivers available at the MCC for direct RF reception. Hardwire transmission over these lengthy cables was felt to contribute appreciably to noise and unreliability. The display of launch vehicle data to the MCC is listed as follows:
  a. Abort bus signal.
  b. Attitude error, abort.
  c. Angular velocity, abort, pitch.
  d. Control voltage abort.
  e. Abort from capsule.
  f. Angular velocity, abort, yaw.
  g. Combustion pressure cutoff switch No. 2.
  h. Combustion pressure cutoff switch No. 1.
  i. Tilting program, LEV-3.
  j. Input to flight sequence.

k. Gyro pitch position, minus program.

l. Acceleration of missile, longitudinal.

m. Acceleration of missile, fine, longitudinal.

- To assure that the best information from qualified sources was available within the shortest possible time, the following ground rules were established:

  a. The MCC console was monitored by the MSFC Project Director and an LOD measuring engineer.

  b. The measuring engineer forwarded booster information to the Flight Director after verification with the blockhouse on any of his observations within 15 seconds, depending upon circumstances.

  c. The blockhouse booster performance display was monitored by the Deputy Director and Deputy Chief, Measuring and Tracking Office.

  d. The blockhouse had the capability of selecting telemetry receiving stations to assure the best available data.

  e. The MCC did not take command action solely on the basis of MCC booster performance data.

### 7.5.5.6 Communications for Recovery

The communications transceivers aboard the capsules could have been used as a backup homing signal for the ships, helicopters, and aircraft of the recovery force. A UHF SARAH (search and rescue and homing) beacon and an HF SEASAVE beacon were carried on the capsules for homing purposes after re-entry; two UHF and two HF voice transceivers were also carried. On the unmanned flights, recorded messages were transmitted from the capsule. Communications were maintained between capsule, Cape MERCURY Control Center, GBI, and the recovery force.

### 7.5.5.7 Abort Landing Predictor

One support system of interest was the Abort Landing Predictor. Because of the slow rate of descent and the resulting high wind drift of a MERCURY capsule, the usual impact prediction method was not considered adequate. Using winds aloft data, available at T-5, 4, and 2 hours, the LOD Burroughs 204 computer was programmed to calculate the capsule landing points, assuming an abort occurred at intervals of four to eight seconds during a normal booster flight. A trace of the abort landing points, with corresponding times, was given to the MERCURY Control Center. Had there been an abort, personnel could have obtained an approximate landing point by observing

the recorded abort time and the plotted landing point. Information thus provided, permitted the MERCURY Control Center to determine whether a Cape abort would result in an unsafe area, and hold the count pending more favorable wind conditions, if necessary.

## 7.6 METEOROLOGICAL ASPECTS

### 7.6.1 GENERAL

Weather input to the MERCURY-REDSTONE Program was a divided responsibility. The Atlantic Missile Range, the MERCURY network, and the MERCURY recovery forces, all supplied observational data. Forecasts were supplied by the Project MERCURY Weather Support Group of the United States Weather Bureau. While a small duplication of capability existed in this arrangement, there is no question of the need for the additional worldwide meteorological support that Project MERCURY Weather Support Group provided, especially weather information about recovery areas, and extended-range forecasts.

### 7.6.2 WEATHER RESTRICTIONS

#### 7.6.2.1 General

Weather restrictions that affected the MERCURY-REDSTONE Program may logically be grouped into two categories as follows:

- Nominal mission restrictions.
- Aborted mission restrictions.

#### 7.6.2.2 Performance Restrictions

Performance restrictions are those which might affect the performance of the spacecraft and booster combination in a normal mission. This group may be subdivided into three categories: (1) the booster-capsule combination during launch phase, (2) the capsule's capability of surviving a landing, and (3) the capability of successfully recovering the capsule.

#### 7.6.2.3 Arbitrary Restrictions

The restrictions of this category were those which have no specific effect upon the successful completion of an operation, but became of upmost importance if a failure occurred during the boost phase. Optimum optical observation of the booster-capsule

combination through the zones of maximum dynamic pressure and through the separation of the escape systems was mandatory for a manned flight.

### 7.6.3 WEATHER MINIMUMS

The MERCURY-REDSTONE booster itself was subject to easily satisfied weather minimums in the Cape Canaveral launch area. Required weather minimums are as follows:

- Precipitation occurring during the launch countdown phase could hamper certain launch preparations such as liquid oxygen tanking.
- Lightning storms present a hazard to missile preparation, particularly relating to ordnance devices.
- Ground winds, especially gusts, are a limiting factor after removal of the service structure. An 18-knot (sustained) or 25-knot (gust) wind limitation was the standard used for all MERCURY-REDSTONE operations. Winds of higher velocity than this were experienced only about 10 percent of the time.
- Winds aloft, at the prevailing level of the jet stream placed the most severe limitations upon the MERCURY-REDSTONE. The critical speed is a function of both direction and speed, as well as vertical shear. During the cooler months, winds aloft are sufficiently strong on about 30 percent of the time to require flight simulation before conducting launch operations, but only about 10 to 15 percent of the time are winds sufficiently strong to prevent launching. During the warm months upper winds are not a factor. Once a strong jetstream maximum becomes established over the Cape Canaveral area, it is characteristic that it persists for several successive days. Critical periods arising out of strong winds aloft, alternating with periods of no upper wind problem, last up to a week or more. Such conditions lend themselves to reasonably reliable prediction.

### 7.6.4 SURFACE WINDS

The MERCURY capsule was subject to a variety of weather restrictions, most important of which is the surface wind and its attendant state of the sea. Structural limitations and the capsule's relatively small size limit its capability of surviving a landing in rough seas. Since an abort off the pad, or during the boost phase, might result in a landing at any point along the planned trajectory or in the immediate vicinity of the launch pad, wind and sea state minimums must be satisfied all along the range. The

frequency of limiting winds and seas in the Cape Canaveral area or along the trajectory is not high, but may occur in connection with a great variety of synoptic weather patterns, at any time during the year (most frequently during the cool months).

### 7.6.5 CEILING AND VISIBILITY

Successful recovery leads to even more weather limitations. The limit of wind and sea state applicable to a safe landing is critical for safe recovery. Since recovery may involve an aircraft search phase, the elements of ceiling and visibility in the recovery area are also critical. The frequency of unfavorable ceiling and visibility that would hamper search operations are relatively low.

### 7.6.6 OPTICAL COVERAGE (CLOUDS)

The total amount of sky coverage of the Cape Canaveral area exceeds 40 percent more than half the time, with no great variability in the mean throughout the year. Cloudiness in excess of 30 percent was selected as the limiting factor, but only as a starting point. Capability of the cameras to track a rising missile is virtually unpredictable. This capability is dependent upon many factors other than the amount of cloudiness present at a given time. It has been known to range from less than 20 percent capability under sky coverage of less than 1/10 all the way to 80 percent capability under 7/10 opaque sky. Only under conditions of clear sky, or 10/10 opaque cloud coverage, could camera capability be predicted accurately.

The MERCURY-REDSTONE Programenjoyed more than a fair share of good weather conditions. Of nine scheduled launches that proceeded to within one hour of planned launch time, weather conditions were a factor in four launches, two of which were scrubbed because of weather. In every case of weather limitation, optimum optical coverage was the problem. It is noteworthy that the four cases, in which weather necessitated cancellation or delay, occurred during the warm season; whereas, those unaffected by weather occurred during the colder months. Weather during the cooler seasons tends to run in cycles of excessive cloudiness alternating with clear skies within periods of several days, consistent with the movement of major fronts across North America. There is no such consistent relationship during the warmer months; thus, the winter-time phenomena lend themselves to a much more reliable prediction. While weather delays were not necessary during the launches scheduled for the cooler months, strong jet stream level winds were a definite threat on two occasions, and surface wind conditions in recovery areas barely subsided to acceptable limits on another occasion.

### 7.6.7 METEOROLOGICAL SUPPORT

Within the limits of forecasting capability, meteorological support to the MERCURY-REDSTONE Program left little to be desired. Prediction of moment-to-moment variability in sky condition, such as occurred at the launch site during the last few hours of the countdown of both MR-3 and MR-4, is not feasible. Aircraft reconnaissance of the near vicinity is of inestimable value in the case of middle or high cloudiness, but serves little purpose for low clouds, which have a tendency to form over the Cape area rather than being carried over by the prevailing winds. Clouds of the latter variety present no real obstacle to system performance but are most restrictive to optical tracking. Project MERCURY Weather Support Group's radar compositing technique, involving WSR-57 equipment at Miami, Tampa, and Daytona Beach, proved to be a very useful means of keeping under surveillance large-scale convective disturbances beyond the range of a single radar at Cape Canaveral.

SECTION 8

# FLIGHT TEST PROGRAM

## 8.1 INTRODUCTION

The flight test program consisted of six flights in three phases. The first three flights provided checkout and data for both capsule and launch vehicle designers. The fourth flight was a final booster development test prior to the manned shots. The last two flights were the manned operational flights providing the suborbital testing of the MERCURY capsule. Table 8-1 is a summary of the flights.

Table 8-1
Summary of the MERCURY-REDSTONE Flight Test Program

| Flight Number | Launch Date | Booster Number | Capsule Number | Payload |
|---|---|---|---|---|
| MR-1 | 21 Nov 1960 | MR-1 | S/C - 2 | Simulated man |
| MR-1A | 19 Dec 1960 | MR-3 | S/C - 2 | Simulated man |
| MR-2 | 31 Jan 1961 | MR-2 | S/C - 5 | Chimpanzee- "Ham" |
| MR-BD | 24 March 1961 | MR-5 | Boilerplate | |
| MR-3 | 5 May 1961 | MR-7 | S/C - 7 | Astronaut Alan Shepard |
| MR-4 | 21 July 1961 | MR-8 | S/C - 11 | Astronaut Virgil Grissom |

| Parameters | MR-1A | MR-2 | MR-BD | MR-3 | MR-4 |
|---|---|---|---|---|---|
| Flt path ∠ at cutoff (deg fr local vert) | 41 | 40.4 | 41 | 41 | 41 |
| Velocity at cutoff, space fixed (ft/sec) | 7200 | 8590 | 7514 | 7388 | 7580 |
| Maximum altitude (nautical miles) | 113.56 | 136.43 | 98.63 | 101.24 | 102.76 |
| Range (nautical miles) | 204.0 | 363.0 | 276.1 | 263.1 | 262.5 |
| Maximum Dynamic Pressure ($lb/ft^2$) | | 576 | 556 | 586 | 605 |
| Thrust, Sea level (lbs) | | 82,680 | 78,780 | 78,860 | 79,220 |
| Engine Specific Impulse, Sea level (sec) | | 217.2 | 216.3 | 214.8 | 217.4 |
| Weight, liftoff (lbs) | | | 66,116 | 66,098 | 65,976 |
| Launch Time (EST) | 1115 | 1154 | 1230 | 0934 | 0720 |
| Launch time delay, veh caused, (min) | 0 | 74 | 0 | 53 | 0 |

Table 8-1

Summary of the MERCURY-REDSTONE Flight Test Program (Cont'd)

| Parameter | | MR-BD | MR-3 | MR-4 |
|---|---|---|---|---|
| Pitch | (% abort limit) | 16 | 17 | 20 |
| Roll | " | 34 | 12 | 12 |
| Yaw | " | 29 | 13 | 24 |
| Pitch rate | " | 35 | 22 | 50 |
| Yaw rate | " | 14 | 14 | 14 |

The flight program described in this section pertains only to that of the MERCURY-REDSTONE booster. There were two other MERCURY flight test programs being conducted during this same period. One of these was a capsule separation and abort checkout program using LITTLE JOE booster. A total of seven flights and one beach abort test were made. In addition, a MERCURY-ATLAS development program was being conducted simultaneously with one BIG JOE and three MERCURY-ATLAS flight attempts occurring before the final MR-4 flight.

## 8.2 DEVELOPMENT FLIGHTS

### 8.2.1 GENERAL

The first three MERCURY-REDSTONE flights, MR-1, -1A, and -2, were development flights to prove the adaption of the REDSTONE to the MERCURY suborbital mission and the interfaces with the MERCURY capsule. All flights were made from Launch Complex 56 at Cape Canaveral, Florida. In addition to testing the booster and capsule, these flights prepared the launch personnel for the manned flights to follow. A discussion of the launch operations will be found in Section 7 of this report. As noted, for half of the flights (MR-1, -1A, and -BD), the abort sensing system was flown open loop, that is, no abort would occur even if conditions required an abort. This was done to preclude a mission failure due to a malfunction of the abort system.

MERCURY-REDSTONE Flight MR-1 was launched on 21 November 1960 from Pad 5 of Launch Complex 56. The primary mission was to obtain an open loop evaluation of the automatic inflight abort sensing system and to qualify the spacecraft/launch vehicle combination for the MERCURY ballistic mission, which included obtaining Mach 6.0 during the powered portion of the flight and successful spacecraft separation.

Prior to the launch on 21 November, a launch attempt was made on 7 November 1960. This attempt was scrubbed at T-22 minutes when a low hydrogen peroxide pressure indication in the capsule was discovered. Previously, a 60-minute hold at T-120 minutes was made to correct difficulties with the spacecraft's hydrogen peroxide system.

MR-1 was the combination of Booster MR-1 and Spacecraft 2. The firing command was given from the blockhouse at 0859 EST and normal ignition occurred. At first motion of the vehicle an engine shutdown signal was given. Prior to complete shutdown the thrust was sufficient for MR-1 to rise 3.8 inches, then settle back on the pedestal. The engine shutdown signal also caused the capsule escape tower to be jettisoned. Still surrounded by the smoke created by the jettison rockets the vehicle tilted slightly on its pedestal, but remained erect. The capsule's drogue chute deployed, then its main parachute, and finally the auxiliary chute. Still attached to the capsule, which had remained on the booster, the chutes fell to the pad. (Figure 8-1.)

After the first three seconds, the vehicle rested on the launch pedestal, fully fueled and armed. Liquid oxygen was venting and the fin frames were deformed due to the force of impact. No power or command connections with ground support equipment remained after liftoff; therefore, no control could be exercised over the booster or the capsule. To prevent further damage, especially the possibility of accidental signaling of the destruct system, range safety left the command carrier on throughout that day and the following night to insure saturation of the receivers thereby blocking them from detecting any spurious signals.

The vehicle was allowed to remain on the pad to evaporate the liquid oxygen. The following morning the LOX tank was vented, as were the high-pressure nitrogen spheres in the engine pneumatic system. The fuel and the hydrogen peroxide tanks were then emptied. All circuits were deactivated, the service structure was moved into place, and lastly the destruct system arming device and primacord were removed.

The investigation which followed found the cause of the engine shutdown to be due to a "sneak" circuit created when the two electrical connectors in Fin II disconnected in the reverse order. Normally the 60-pin control connector separates before the 4-pin power connector. However, during vehicle erection and alignment on the launch pedestal, a tactical REDSTONE control cable was substituted for the specially

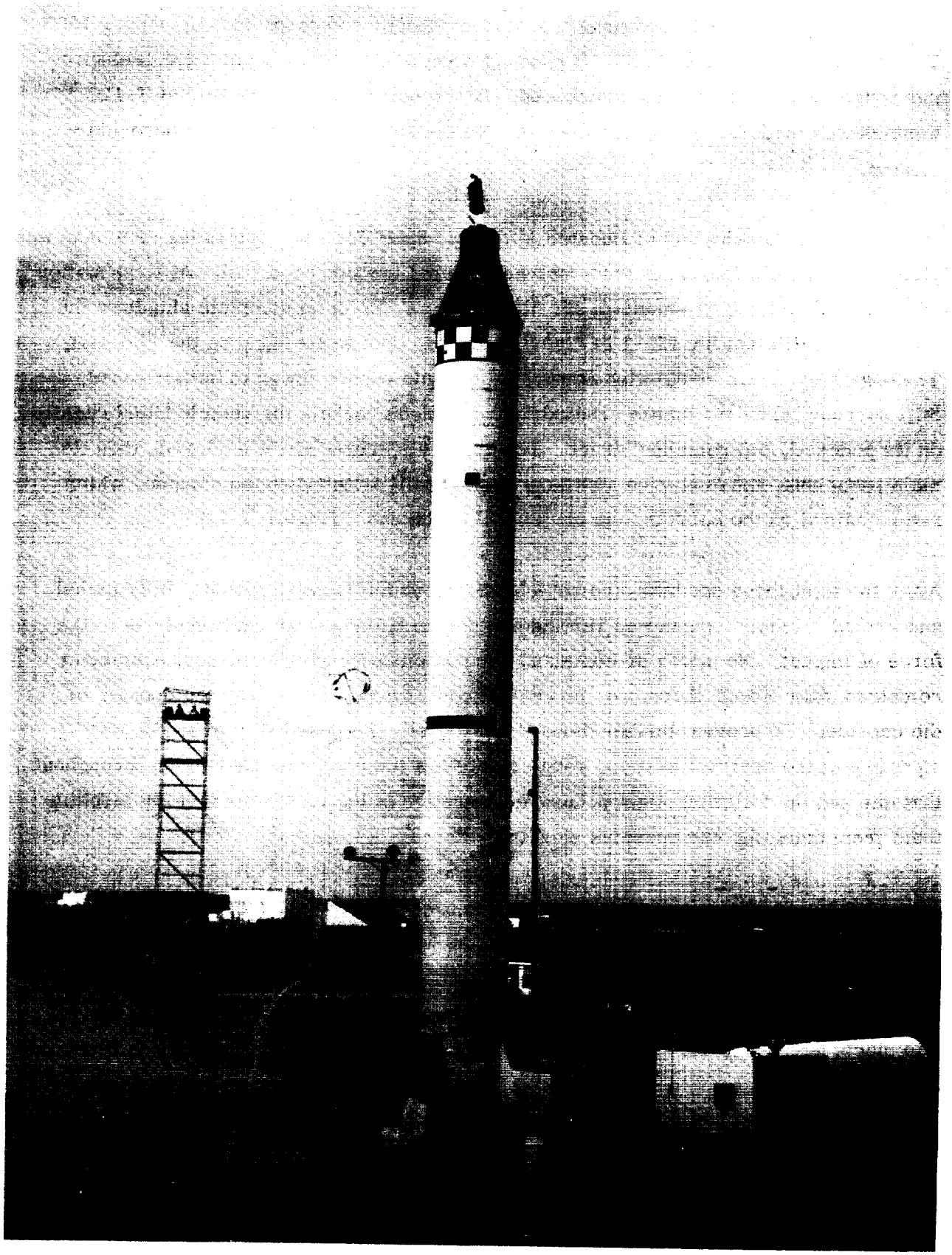


Figure 8-1. MERCURY-REDSTONE MR-1 During Parachute Deployment

shortened MERCURY cable. The cable clamping block was then adjusted, but apparently not enough to fully compensate for the longer REDSTONE cable.

Because of the improper mechanical adjustments, the power plug disconnected 29 milliseconds prior to the control plug. This permitted part of a three-amp current, which would have normally returned to ground through the power plug, to pass through the "normal cutoff" relay and its ground diode. The cutoff terminated thrust and jettisoned the escape tower.

The spacecraft did not separate from the launch vehicle because the g-load sensing requirements in the spacecraft were not met. "Normal cutoff" started a 10-second timer which, upon its expiration, was supposed to signal separation if the spacecraft acceleration was less than 0.25g. (This sequencing was designed to minimize the occurrence of a spacecraft launch-vehicle recontact.) However, MR-1 had settled on the pad before the timer expired and the g-switch, sensing lg, blocked the separation signal.

The barostats properly sensed that the altitude was less than 10,000 feet and therefore actuated the drogue, main, and reserve parachutes in the proper sequence. The reserve parachute was released because no load was sensed on the main parachute load sensors.

To prevent a second occurrence of this problem a "ground strap" approximately 12 inches long was added to maintain vehicle grounding throughout all liftoff disconnections. Changes were also made in the electrical network distributor to prevent a cutoff signal from jettisoning the escape rocket and tower prior to 129.5 seconds after liftoff; for by jettisoning the tower on the pad, the abort mode of escape was lost and a potentially hazardous condition would have existed if the flight had been manned. This safety measure was accomplished by modifying the flight sequencer to generate an arm cutoff to capsule signal. If the pressure in the combustion chamber was normal at 129.5 seconds and the capsule cutoff circuit was armed, a normal booster cutoff signal could then be received by the capsule to start the tower jettison sequence. An arm cutoff to capsule signal switch was also added to the blockhouse propulsion panel.

Examination of the booster and capsule indicated both could be reused after refurbishment. Since the capsule was not damaged it was subsequently used on MR-1A.

However, MR-1's tail assembly sustained minor damage so it was decided to use booster MR-3 for the next flight. MR-1 was then returned to MSFC where it was held in reserve. At the conclusion of the program, MR-1 remained at MSFC and is now on display at the Space Orientation Center. Table 8-2 lists the sequence of events for the MR-1 flight.

Table 8-2
MR-1 Sequence of Events

| Event | Range Time (+0.001 sec) | Comment |
|---|---|---|
| First Motion | 0.600 ±0.025 | Cutoff condition generated |
| Power plug disconnect | 0.609 | |
| Cutoff (system signal) | 0.617 | |
| Cutoff (measuring signal) | 0.635 | |
| Control plug disconnect | 0.639 | |
| Liftoff (measuring signal) | 0.648 | |
| Abort bus energized | 0.752 | |
| Escape tower jettison | 0.775 ±0.010 | |
| Telemetry interference due to jettison rocket exhaust | 0.775 - 1.1 | |
| Chamber pressure decays to 0 | 1.3 - 1.4 | |
| Recovery system armed, and drogue chute deployed | 3.775 | |

### 8.2.2 FLIGHT MR-1A

Flight MR-1A was composed of the MR-3 launch vehicle and the No. 2 spacecraft. The flight achieved the mission objectives set for MR-1. The capsule was the same one used on flight MR-1 except for replaced parts and minor modifications, such as, a tri-nozzle on the tower jettison rocket and the resetting of the parachute deployment backup barostats at 21,000 feet. The capsule was mated with the launch vehicle on 8 December 1960, and the simulated flight test was successfully run on 17 December 1960. Launch procedures were arranged in a split countdown of 250 minutes on 18 December and 360 minutes on the following day. The second part was started at 0222 EST but a leakage in the capsule's high pressure nitrogen line and a faulty solenoid valve in the peroxide system of the capsule required correction causing a launch delay of three hours and 15 minutes.

At 1115 EST on 19 December 1960, the space vehicle was launched from Launch Complex 56 and successfully met its objectives (Figure 8-2). During the flight all abort measurements remained between the limits and the abort system functioned as expected. Malfunction of the velocity integrator, however, caused the vehicle velocity cutoff to be 260 fps higher than normal, thus boosting the capsule 6 miles higher than the predicted 128 miles and resulted in a capsule re-entry deceleration approximately 0.4 to 1.0 g above the predicted 11.0 g maximum. The capsule also traveled 20 miles further downrange than predicted. High tail winds (up to 203 feet per second) and the "popgun effect" at separation were also contributing factors to the increased range and deceleration.

A thorough laboratory check of the integrator was made and the source of the malfunction identified as excessive torque against the pivot of the accelerometer caused by eight electrical wires. Relocation of five of the wires and use of a softer wire material (85 percent silver, 15 percent copper) on the remaining three wires solved the problem as demonstrated by the MR-2 and MR-BD flights. A backup cutoff timer was also used during these flights, but it was removed for MR-3 and MR-4 because the modified velocity integrator operated properly.

The abort system was also flown open loop on MR-1A. All sensors showed levels well below the abort limits, and the system was de-energized at engine cutoff, as designed. The pitch abort sensor indicated an abort condition of 5.4 degrees some 7.6 seconds after engine shutdown. The condition was attributed to nose-up thrust from the LOX vent.

High LOX flow coupled with low fuel flow gave an oxidizer to fuel mixture ratio 3.6 percent higher than predicted; however, the residual propellants were sufficient to insure full duration of engine operation.

Vehicle control was proper throughout powered flight, but small amplitude vibrations were measured. The first mode frequencies of 3.5 cps appeared during the first 10 seconds of flight. The second mode frequencies occurred randomly and varied from about 6.5 cps near liftoff to about 9 cps at cutoff. The angle of attack reached a maximum of 6.0 degrees.

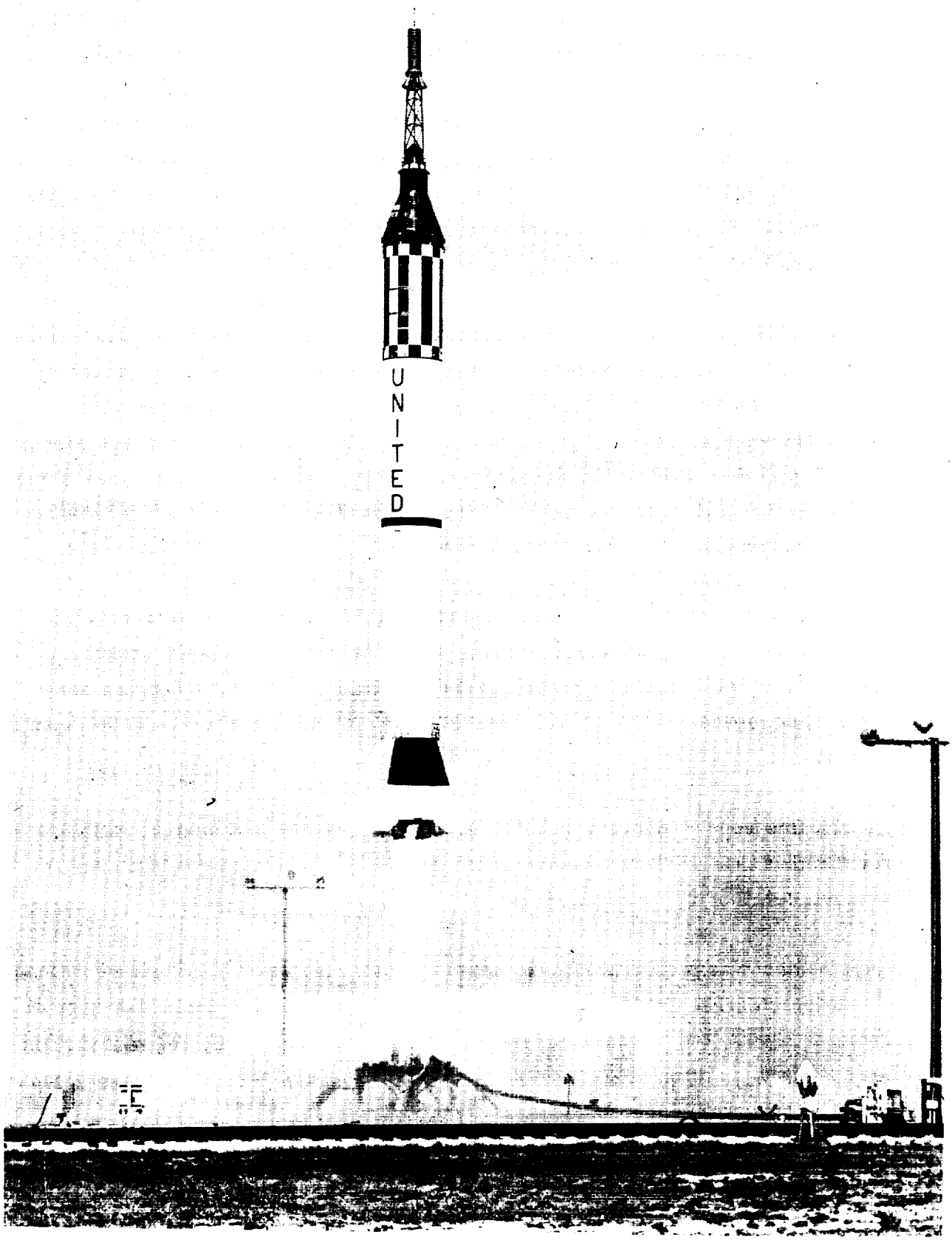



Figure 8-2. Liftoff of MERCURY-REDSTONE MR-1A

A vibration transducer was located on the abort rate switch mounting bracket in a longitudinal direction and another was mounted in a lateral direction on the capsule adapter mounting ring. The vibrations indicated by both transducers were approximately the same throughout powered flight; i.e., ignition was reflected by a sharp increase in acceleration levels as was the liftoff phase. The vibrations attained a maximum of 4.5 g's during liftoff (over-all) then decreased to a negligible magnitude at 10 seconds. At 30 seconds, the vibrations gradually increased to another maximum at 70 to 80 seconds. This latter maximum exceeded the range of the sensors but showed predominant frequencies in the 500 to 1200 cps area. The vibratory acceleration level then decreased gradually and by 130 seconds was again negligible. Cutoff and separation showed a normal transient. Since the measured vibration spectrum was mostly in the high frequency range, the vibration levels were not considered critical.

MR-1A encountered a 13-minute hold at T-200 minutes to change the capsule high pressure line and 100-minute hold at T-60 minutes to replace an attitude control nozzle in the capsule. Due to the length of this latter hold the countdown was recycled to T-120 minutes.

### 8.2.3 FLIGHT MR-2

On 31 January 1961, MR-2 was launched at 1154 EST from Cape Canaveral and successfully placed into space a 37-pound male chimpanzee, named Ham. This was the first flight test of the capsule's life support system and the first flight to carry a primate into space. The launch was successful, but the capsule, programmed to travel 114 miles high and 291 miles downrange, traveled 42 miles higher into space and 124 miles farther downrange than planned. Despite re-entry forces up to 15 g's as well as a 6.5-minute period of weightlessness, Ham performed his tasks throughout the flight and survived in excellent condition. The capsule and its passenger were recovered approximately three hours after landing in the sea.

Analysis of the flight revealed that the mixture ratio servo control valve failed in the full-open position causing early depletion of the LOX. The propellant consumption rate was also increased by hydrogen peroxide pressure which drove the turbopump faster. Both conditions resulted in high thrust, early shutdown, and an inadvertent capsule abort.

The abort was due to timing within the abort sensing system. The abort pressure switches were timed to be transferred from the abort mode to the normal shutdown mode at 137.5 seconds. This was 5 seconds before normal expected shutdown. However, the early depletion of LOX shuts down the engine at 137 seconds, one-half second before the pressure switches were transferred. Thus, the decrease in chamber pressure was interpreted as a malfunction, and the abort sensing system signaled abort. To correct the problem on the remaining flights the abort chamber pressure sensors were switched to the normal shutdown mode at 135 seconds, 2.5 seconds earlier than before.

At shutdown the vehicle had a velocity 659 fps above normal due to the higher thrust. To this was added 492 fps gained from the firing of the abort rockets. During the abort the retro rockets were properly jettisoned, but these would have remained attached to the capsule during a normal flight and decreased its velocity by 460 fps. Thus, the capsule had a velocity 1611 fps higher than normal, resulting in the extensive departure from the planned trajectory.

Analysis of the mixture ratio servo control valve showed that movement from the 100 percent open position occurred three times and that the valve probably did not stabilize at a somewhat closed position as a result of (1) a gas leak in the transducer sensing line, (2) icing in the transducer sensing line, and/or (3) shifting of the null setting. The higher than expected hydrogen peroxide tank pressure was probably due to pressure regulator tolerance which was ±5 percent in the 0 to 600 psig range (or ±30 psi). Since this is normally acceptable no changes were made in the regulator setting.

All measured data from the abort system sensors, except for the chamber pressure which gave the actual abort, showed levels below the abort limits. As expected, the pitch attitude abort limit of 5 degrees was reached approximately 8 seconds after engine cutoff.

The space vehicle was properly controlled throughout powered flight. The profile varied less than 3 degrees below the pitch program and was 1 degree above the expected final angle of 40 degrees. Structural oscillations of the second bending mode were still present in pitch and yaw during power flight. The maximum amplitude occurring from 100 to 135 seconds, was 0.35 degree per second and represented a nose deflection of 0.02 inch.

The measured deflection of vane No. 1 was approximately 0.8 degree during the period of 125 to 135 seconds.

A narrow band analysis was made of the lateral and longitudinal vibration measurements and the resulting spectra indicated high frequency levels, and, therefore, were probably of aerodynamic origin. The lateral measurement on the capsule mounting ring gave a maximum level at T + 1.5 seconds due to ignition and liftoff, but the level was beyond the setting of the sensor. The vibrations decreased to a negligible magnitude until 22 seconds then began a gradual buildup to another maximum between 70 and 80 seconds, to a saturated level, then decreased to a negligible magnitude at 125 seconds and remained at this level until cutoff and separation where it showed a normal transient. The longitudinal measurement on the LEV-3 platform which had previously been mounted on the rate switch bracket, indicated a sharp increase in vibration level immediately after ignition and during the liftoff phase. At 1.5 seconds a maximum over-all value of 4.7 g's occurred and then the level decreased to an insignificant value at 5 seconds. At 25 seconds, the level gradually increased until it reached a maximum saturated value at about 70 seconds. The vibration then became negligible at 110 seconds where it remained until 138 seconds when it showed a normal cutoff and separation transient.

The vibration analysis described above was necessary to evaluate the interaction effects between the vehicle's second bending mode and the control system. The control system had been successfully used on the REDSTONE and thus was selected for the MERCURY flights. However, due to the increased vehicle length and heavier payload, the natural bending frequency of the MERCURY-REDSTONE decreased by a factor of four. This made the second bending mode frequency critical with respect to the stability frequency of the control system. Figure 8-3 shows these vibrations as recorded on a strip recorder. The solution to this problem was the addition of a filter network in the control computer. This filter reduced the control loop gain between 6 and 10 cps, the frequency of the second bending mode.

Flight MR-2 was composed of the MR-2 launch vehicle and Capsule No. 5. The launch vehicle tank section was distorted by unequal pressure during air transport because the tarpaulin plugged the breather vent; the launch vehicle was immediately returned to MSFC where it was partially corrected for geometry and thoroughly checked for structural adequacy, including X-ray inspection of welds. Everything having been found acceptable, the launch vehicle was returned to the Cape. The launch vehicle and

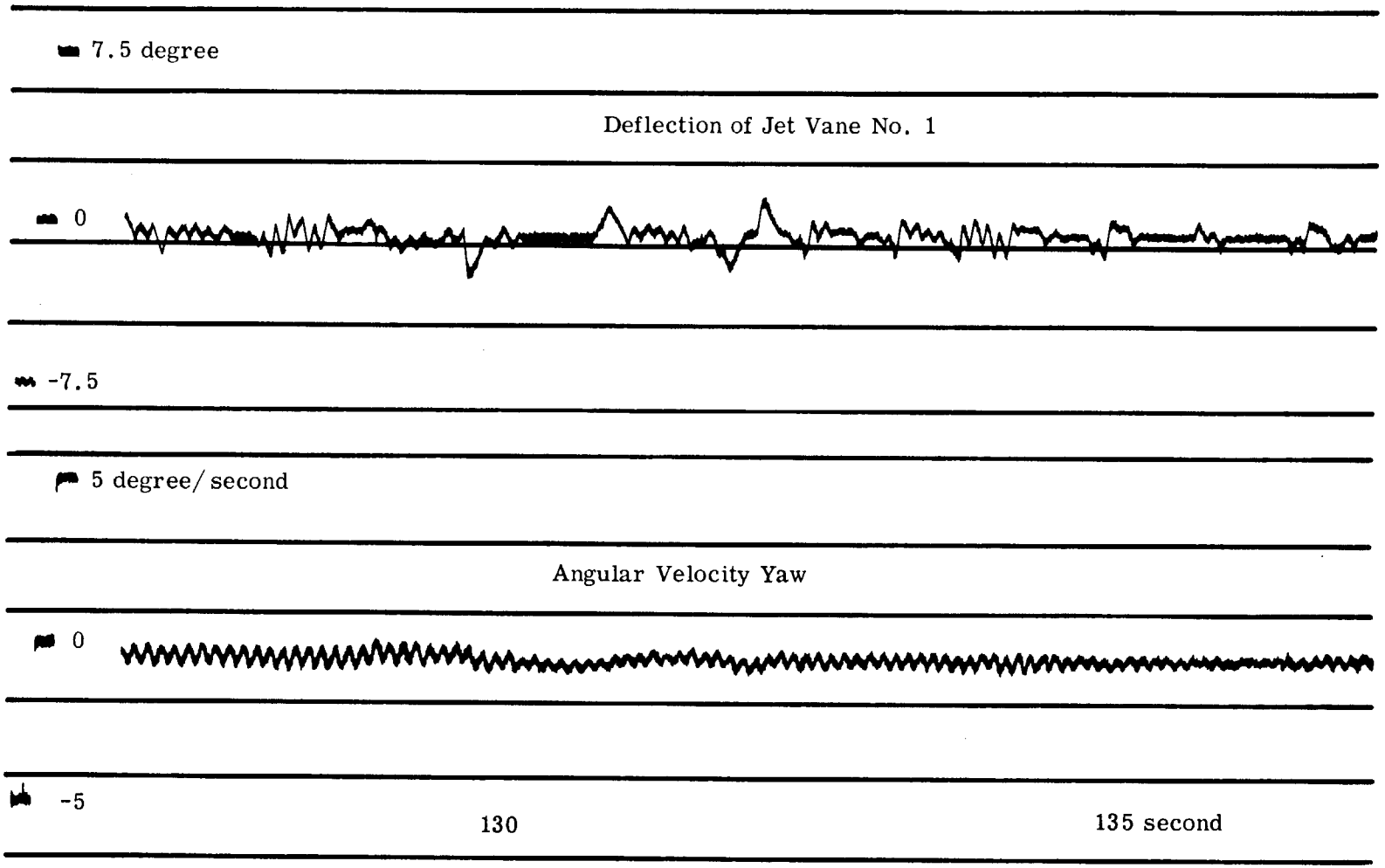



Figure 8-3. Second Bending Mode Oscillations in Yaw Toward End of MR-1A Flight

the capsule were mated on 19 January 1961, and the simulated flight test was conducted on 27 January 1961. A divided countdown was again used to minimize fatigue of the launch personnel. The first part was conducted from 0630 to 1040 EST on 30 January 1961. The second part was started at 0130 EST the following day with a total of 3 hours and 55 minutes hold and recycle time due mainly to resetting the torsion spring on the tail control plug cap of the launch vehicle and to cool the capsule inverter. The holds were as follows:

- At T-260 minutes, 13 minutes - To catch up on vehicle work (8 minutes) and complete tuneup of range command system (5 minutes).
- At T-230 minutes, 17 minutes - By the range to recheck S-band radar.
- At T-170 minutes, 6 minutes - To remove nonessential personnel from pad.
- At T-35 minutes, 66 minutes - To catch up on vehicle work and to reset the tension spring on the launch vehicle tail control-plug cap.

On the afternoon of the MR-1 launch attempt, officials of AMR suggested that substitute trajectories be looked into for the launch of the second MERCURY-REDSTONE flight. The reasons for this were that the REDSTONE trajectory was too steep a flight over land for uprange safety and that the 105 degrees azimuth was very close to the right impact limit line established by the range. The allowances necessary in the selection of the destruct lines were different in the case of the MERCURY vehicle since the vehicle had different velocity vector turning rates and different aerodynamic characteristics. It was suggested that the MERCURY-REDSTONE trajectory be changed to one which was flatter during the propelled flight and that the azimuth be changed to 102 degrees. The trajectory for MR-1A was the same as the MR-1 trajectory. Not until the MR-2 flight, did the above changes become active.

### 8.2.4 THE MR-BOOSTER DEVELOPMENT FLIGHT (MR-BD)

The first three MERCURY-REDSTONE vehicles were launched within a 10-week period. As expected, they uncovered several problems and weak areas in the design. For each of the problems and design weaknesses a solution had been developed. Several of these solutions, but not all, had been tested in flight.

The original schedule called for the fourth flight to be manned; however, a doubt existed with some of the program personnel whether all the "fixes" would work. A decision had to be made at this point whether to follow the schedule or to launch another

test vehicle. This decision was to be a joint decision based on the recommendations from MSFC, STG, and NASA headquarters. MSFC was requested to make a technical recommendation regarding the booster's readiness to fly with a manned payload. Within MSFC, the design divisions were requested to appraise the vehicle. The appraisal was to consider vehicle reliability, all areas of possible failure, and trajectories.

An estimated trend of mission reliability was developed based on all research and development, tactical REDSTONE, JUPITER-C, and previous MERCURY-REDSTONE launches. A second estimate was made based on the numerical range of probability to achieve the booster mission with the MERCURY configuration as composed of "known and flown" subsystems. The probability of booster success, thus estimated by both methods was between 78 percent and 84 percent at a 75 percent confidence level (see paragraph 5.3.2).

Each division prepared a failure appraisal covering past malfunctions, corrective actions taken, and the expected repeatability of probable malfunctions. Special emphasis was placed on the areas which were considered weak spots in the systems. Corrective actions, if any, to correct these weak spots were also recommended. In the areas of structures, propulsion, control, test, quality assurance, and launch operations, a list was prepared of those items which might contribute to future booster failures. This list, Table 8-3, included both components needing attention and procedures and practices requiring improvement.

The Aeroballistics Division reviewed the trajectories with regard to the way in which the mission's performance could be reduced to a more conservative level and still meet the mission requirements specified by STG at the beginning of the program. A trajectory giving the required 5-minute weightlessness but with an 8 g re-entry deceleration was proposed. This trajectory included, for astronaut safety, a shallow powered phase which allowed water impact near the Cape in the event of an abort. This trajectory was rejected by STG and in the end the original trajectory with 5 minutes of weightlessness and 11 g re-entry forces was used for all remaining flights.

Table 8-3

MERCURY-REDSTONE Priority List of Weak Spots
(Includes Appraisals from all Divisions and Project Offices)

| | Priority Points | Action Being Taken |
|---|---|---|
| a. First Priority List (Components) | | |
| (1) Thrust controller | 27.7 | S |
| (2) Vibrations | 20.0 | S |
| (3) Cutoff arming timer | 16.7 | S |
| (4) Abort Sensors | 15.0 | S |
| (5) Hydrogen peroxide regulator (tank pressure) | 8.2 | S |
| (6) Hydrogen peroxide system cleanliness | 7.5 | * |
| (7) LOX manhole leak | 5.6 | S |
| b. Second Priority List (Components) ( 5 points or less) | | |
| (1) Velocity integrator | 3.0 | * |
| (2) Instrument compartment pressure | 3.0 | X |
| (3) Control relay box | 2.5 | X |
| (4) Inverter | 2.2 | X |
| (5) Vane nulling if failure | 2.1 | X |
| c. Procedures (no priority order) | | |
| (1) Emergency egress (Cape) | | S |
| (2) Personnel fatigue (Cape) | | S |
| (3) Handling and packaging | | S |
| (4) Cleaning procedures | | * |
| (5) Schedules interference (Cape) | | S |
| (6) TEL 3 - blockhouse communications (Cape) | | S |

Action Code: S = under study on 15 February 1961
X = no action taken
* = corrected

Priority points = number of listings/average priority

After evaluating the appraisals in Table 8-3, MSFC decided that one additional development flight was necessary. The manned flight was necessary. The manned flight was rescheduled and MR-BD (booster development) was prepared for the next MERCURY-REDSTONE launching.

Flight MR-BD was launched at 1230 EST on 24 March 1961. The booster successfully met its objectives and qualified the changes made in the launch vehicle systems. These changes included the following:

- A control computer filter network was added to reduce the attitude gyro gains from 40 to 160 in the frequency range of the two vehicle bending modes.
- Four stiffeners were added in the ballast section to provide frequency and amplitude dampening.
- The thrust control servo valve closed position was adjusted from 0 to 25 percent open to insure a safe liftoff. During flight the controller performed satisfactorily and always compensated for variations in peroxide tank pressure.
- The hydrogen peroxide regulator was set at 570 psig outlet pressure, down from 590, to prevent over-pressurization of the steam to the turbopump. The pressure monitor range was increased from 600 to 700 psig and a blockhouse monitor installed. A drift limit was established at + 50, - 20 psi.
- The thrust computer and $P_c$ transducer surge suppressor in the engine bay were were protected from LOX leaks by the addition of shields and from heat by the installation of insulation.
- Flight sequencer timing changes were made to prevent the abort experienced on MR-2. These included separation of the velocity cutoff arming signal from the signal which caused switchover of the chamber pressure switches from abort to depletion (normal shutdown) mode. Timer changes were as follows:
  a. 129.5 seconds - Arm normal cutoff signal to capsule (was 136 seconds).
  b. 131 seconds - Arm velocity cutoff (was 137.5 seconds).
  c. 135 seconds - Shift $P_c$ switches from abort to depletion mode (was 137.5 seconds).
  d. 145 seconds - Timer cutoff (was 143 seconds).
  e. Normal expected cutoff remained at 142.5 seconds.
- The roll rate abort sensor was removed from the abort circuit to preclude inadvertent abort due to high roll rates. Roll rate was not hazardous in itself, and the sensor was used only as a redundant backup for the roll angle

sensor. The roll rate was higher than on earlier flights but was less than half of the 12 degree per second abort limit used on the first three flights.

A special experiment was also conducted on MR-BD. This involved a control maneuver to evaluate the effect of higher than normal angles of attack. This control maneuver consisted of a temporary tilt arrest at 20 degrees from vertical for 8 seconds at 78 seconds flight time (Q max). This built up angle of attack to 2.30 degrees. Subsequent prolonged tilting brought the missile back to its programmed flight profile with negligible deviations. The experiment proved that the vehicle could withstand the additional loads and its systems.

To instrument MR-BD's special experiment two jet vanes, position indicators, a $P_c$ sensor, and the capsule mounting ring-lateral, vibration monitor were put on straight channels. The thrust controller error signal output was added to the commutated channel and the abort sensors were commutated.

During flight, low frequency lateral vibrations were again present in the instrument compartment and closely approximated the second bending mode of the vehicle. The maximum vibration occurred during the period of transonic speed, which occurred approximately 70 seconds after liftoff. The capsule mounting ring vibrations monitor, although increased in range, was still insufficient to sense the entire frequency range of vibrations. Vane vibrations were not experienced, and, therefore, it was assumed that the filter network was completely satisfactory.

The television camera was removed from MR-BD to save the hardware for the MR-4 flight.

The capsule attached to MR-BD was a boilerplate. It had equivalent weight, mass distribution, and aerodynamic and bending characteristics of the actual capsule. There was no electrical interface, abort capability or separation, but a breakwire was installed to indicate an inadvertent separation if it occurred (which it did not).

During the countdown additional telemetry checks were made. No holds occurred, but some LOX overflow was experienced during topping. This was caused by sloshing due to 15 to 20 mph winds at launch. Also a 119 knot jetstream at 41,000 feet caused the vehicle to impact approximately 6.2 miles further downrange than anticipated.

## 8.3 MANNED FLIGHTS

### 8.3.1 FLIGHT MR-3

On 4 May 1961 at 0934 EST the United States' first astronaut, Alan B. Shepard, was successfully launched into space in a ballistic trajectory which included 5 minutes of weightlessness (Figure 8-4). All mission objectives were accomplished and no malfunctions occurred. The flight occurred three days after the initial attempt was postponed due to severe weather in the recovery area.

MR-3 consisted of booster MR-7 and the Freedom 7 capsule (Figure 8-5). The split countdown was used, with the first part completed on 4 May, and the second portion resumed at 0300 EST on 5 May.

The booster's propulsion system functioned normally. Cutoff occurred at 141.3 seconds and capsule separation at 141.8 seconds (Figure 8-6). The booster sent the capsule on a flight 115 miles high and 302 miles down the Atlantic Missile Range (Figure 8-7). There was no evidence of second bending mode feedback in the control system. This further proved the effectiveness of the filter network incorporated after the MR-2 flight test. Although Astronaut Shepard reported buffeting during powered flight, telemetry data indicated that the vibration levels were lower than those of flights MR-2 and MR-BD. Prior to the flight, 330 pounds of dampening material was added along with 14 stringers in the ballast unit. These decreased the vibrations; however, it was decided to add more dampening material to the instrument compartment of the next flight booster (MR-4).

Two vibration transducers were installed in the aft unit. Measurement 901, on the capsule adapter ring, measured vibration in the pitch plane perpendicular to the longitudinal axis of the vehicle. Measurement 906, mounted on the LEV-3 support bracket, measured vibration in the longitudinal direction. The calibration range of the measurements was ±30 g's and ±10 g's, respectively. The major results revealed by a detailed analysis of the vibration data measured during flight were:

- The duration of high vibration levels due to aerodynamic excitation was shorter in MR-3 than in earlier flights with similar trajectories.
- The vibration levels in the instrument compartment were distinctly lower than in earlier flights.



Figure 8-4. Liftoff of MERCURY-REDSTONE MR-3

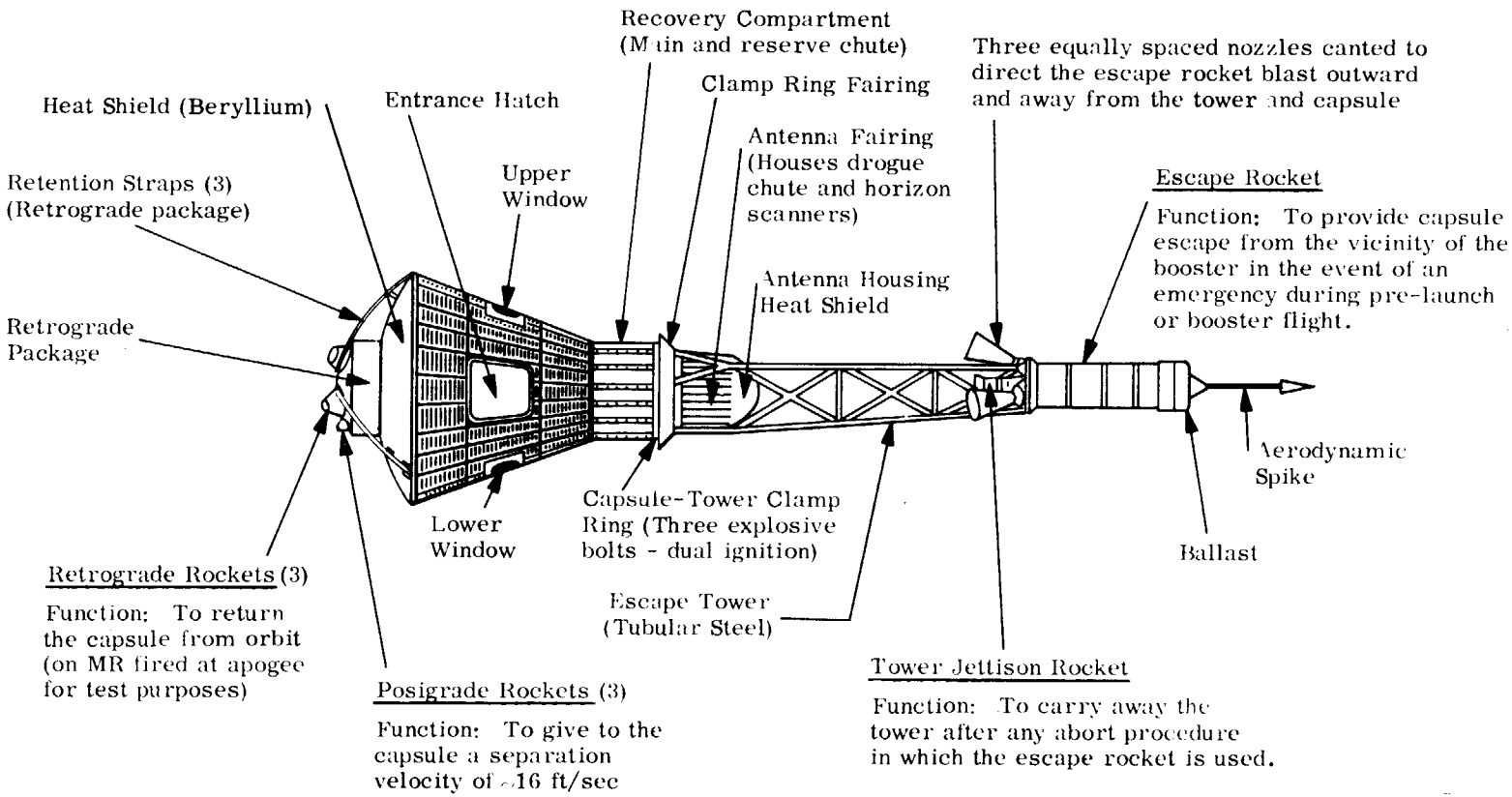



Figure 8-5. MERCURY-REDSTONE MR-3 Capsule Configuration (Capsule No. 7)

- There was a definite 33 cps oscillation in the longitudinal direction at approximately 70 seconds.
- The vehicle was oscillating predominantly in its second-body bending mode throughout the flight.

The launch vehicle shut down properly and capsule separation occurred as expected (Figure 8-8). Astronaut Shepard then assumed manual control of one axis at a time (pitch, yaw, and roll, in that order), and then controlled the vehicle throughout the retro-fire maneuver. Shepard demonstrated that man could control his vehicle both during five minutes of weightlessness and under acceleration loads up to 11 g's. Sensors attached to his body relayed his heart beat and respiration rate to doctors in the control center. During the flight the astronaut maintained radio communications with the control center at the Cape.

After a flight of 13 minutes and 7 seconds, the capsule impacted in the sea three nautical miles from the calculated point. The astronaut and the capsule were recovered by helicopter within six minutes of landing and both were aboard the USS Lake Champlain within eleven minutes.

Seven holds were called during the countdown as follows:

- T-265 minutes, 10.50 minutes to clear the pad for RF checks. (T-140 minutes, the normal 60 minutes hold at this point was shortened to 49.50 minutes to catch up on the count.)
- T-120 minutes, 20 minutes to complete capsule work.
- T-80 minutes, 7 minutes to complete capsule work.
- T-30 minutes, 1 minute to clear the pad.
- T-15 minutes, 34 minutes to evaluate the weather situation and check the booster inverter power supply which drifted out of tolerance. The hold was continued to 52 minutes to replace the inverter.
- T-15 minutes, 17.5 minutes for a computer program check between Goddard and the MERCURY Control Center.
- T-2.66 minutes, 1 minute to decrease the fuel pressure. The fuel vent was cycled several times until regulated pressure returned and stayed normal.

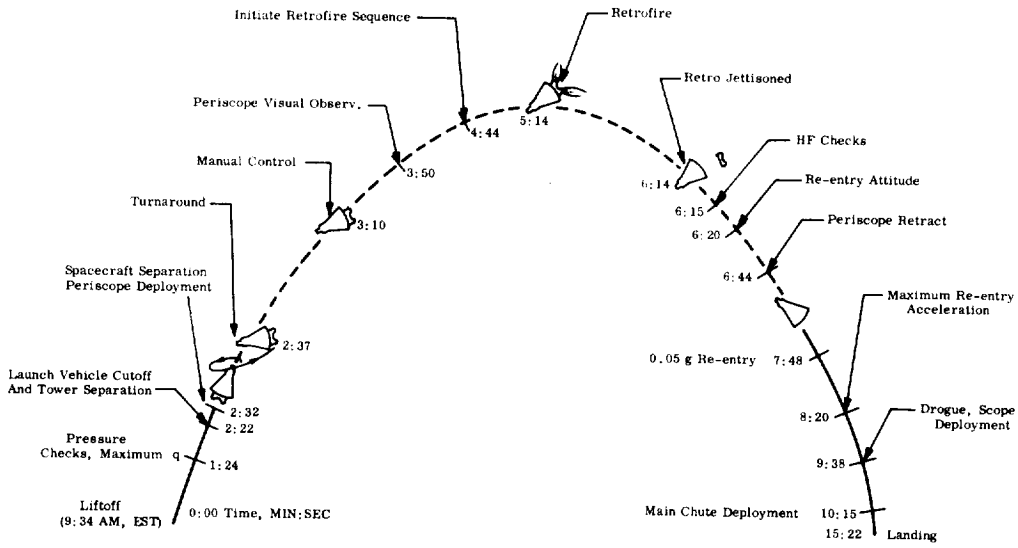
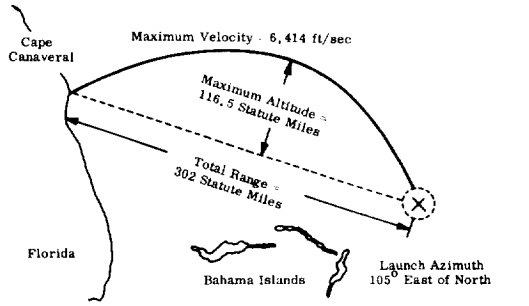



Figure 8-6. MERCURY-REDSTONE MR-3 Flight




Landing Point

| | Long. | Lat. |
|---|---|---|
| Computed | 75° 51' | 27° 12' |
| Actual | 75° 53' | 27° 13.7' |

Figure 8-7. MERCURY-REDSTONE MR-3 Ground Track and Flight Profile

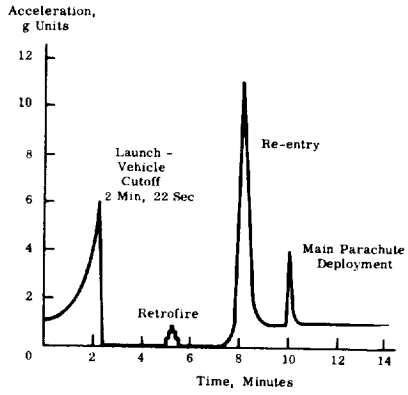



Figure 8-8. MERCURY-REDSTONE MR-3 Acceleration Profile

### 8.3.2 FLIGHT MR-4

Flight MR-4 successfully carried Astronaut Virgil I. Grissom in Liberty Bell 7 on the second manned MERCURY ballistic space mission. Liftoff was at 0720 EST on 21 July 1961 (Figure 8-9). Again all booster systems performed perfectly and all vehicle goals were met.

As with MR-3, the mission objectives were to:

- Familiarize man with a brief but complete flight experience, including liftoff, powered flight, 5 minutes of weightlessness, re-entry, and landing.
- Evaluate man's ability to perform as a functional unit during space flight.
- Collect aeromedical data.
- Safely recover the astronaut.
- Safely recover the capsule.
- Provide training for ground support and recovery forces.

All objectives but capsule recovery were fully met. The capsule was lost when helicopter pickup was unsuccessful due to the increased weight caused by water which had entered capsule after the side egress hatch prematuraly opened.

No complaints of vibration were expressed by Astronaut Grissom, indicating the effectiveness of additional 102 pounds of dampening compound added to the ballast unit.

After the MR-3 flight, the scheduled 60 minute built-in hold was advanced to T-180 minutes instead of T-120 minutes. This change was made to provide the latest possible weather forecast prior to LOX loading. If a favorable forecast, having a validity of 90 percent, could not be determined, LOX loading operations would not have commenced. This procedure (by not LOXing) provided an alternate by 24 hours scheduling.

The first launch attempt on 18 July 1961, had no holds, however, the flight was scrubbed due to unfavorable photographic weather conditions.

The second attempt was made on 19 July. At T-130 minutes, a 30-minute hold was made to complete checkout of capsule equipment. A 9-minute hold at T-60 minutes was required to complete additional capsule work. At T-10.6 minutes a 91-minute hold for better cloud conditions resulted in a scrubbed flight.

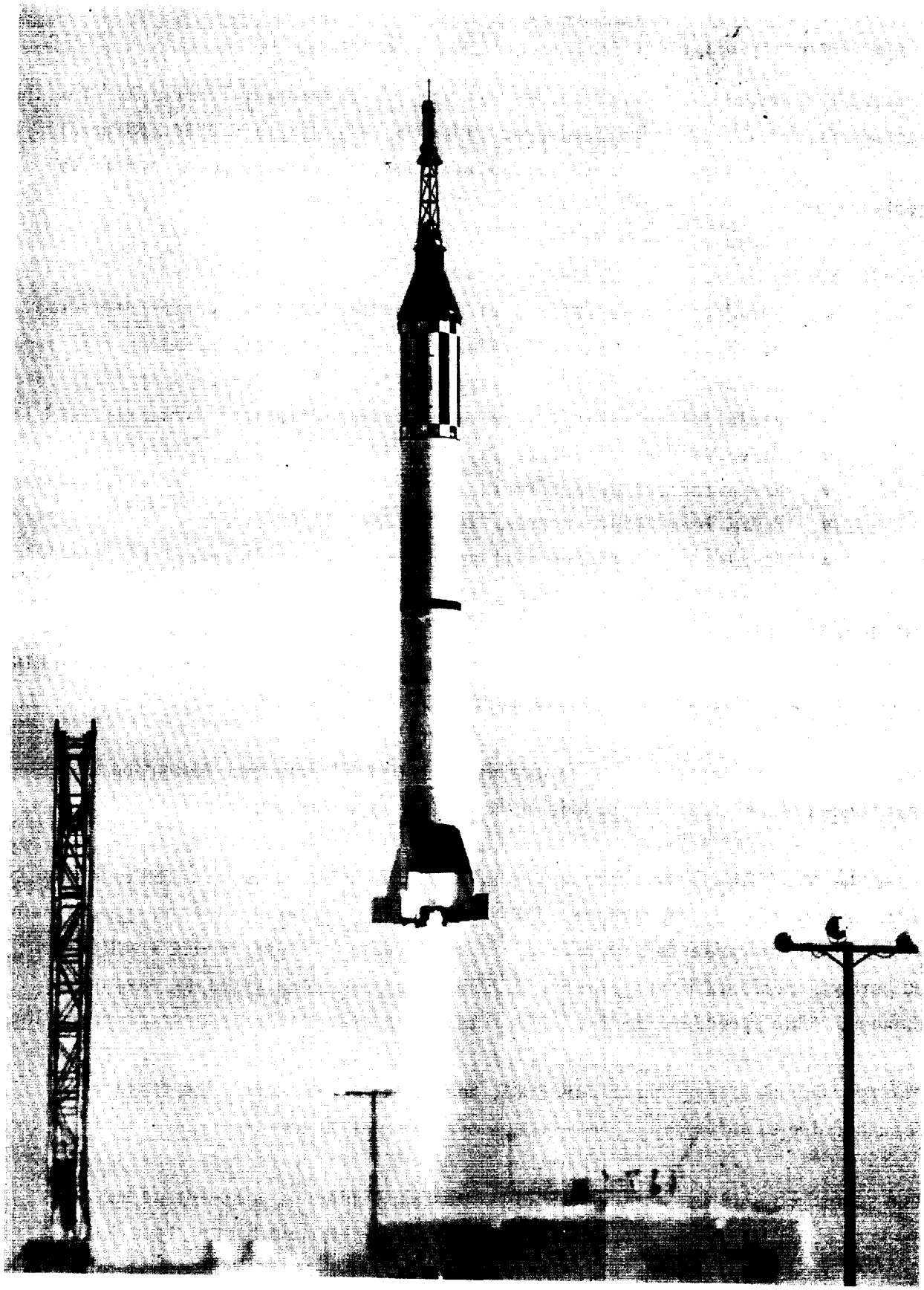


Figure 8-9. Liftoff of MERCURY-REDSTONE MR-4

The third and successful attempt on 21 July had 3 holds of 80 minutes total duration. At T-45 minutes, a 30-minute hold was necessary to permit capsule personnel to complete capsule work. At T-30 minutes, a 9-minute hold permitted the searchlight crew to secure the searchlights because of interference with telemetry receiving equipment in the blockhouse. Finally, at T-15 minutes a 41-minute hold was made to await more favorable optical conditions for the long focal-length cameras.

Figure 8-10 indicates the flight profile. Note that the launch azimuth was changed from the 102 degrees used for MR-2, BD, and 3 to 100 degrees east of north. This change was required because calculations after the MR-3 flight indicated that MERCURY-REDSTONE three-sigma guidance deviations could cause a malfunctioning booster to endanger the Bahama Islands. A comparison of the flight parameters of MR-4 and MR-3 spacecraft, listed in Table 8-4, shows that both flights provided similar conditions.

The acceleration time history occurring during the MR-4 flight is shown in Figure 8-11 and is very similar to that of the MR-3 flight.

The recovery force deployment and spacecraft landing point are shown in Figure 8-12. The spacecraft was lost during the postlanding recovery period as a result of premature actuation of the explosively actuated side egress hatch. The astronaut egressed from the spacecraft immediately after hatch actuation and was retrieved after being in the water for about 3 to 4 minutes.

MR-4 brought to an end the ballistic series of MERCURY flights. Program success permitted the calcellation of two additionally planned MERCURY-REDSTONE flights, and the program moved forward to the orbital flights with the ATLAS booster.

Table 8-4

Comparison of Flight Parameters for MR-3 and MR-4 Spacecraft

| Parameter | MR-3 Flight | MR-4 Flight |
|---|---|---|
| Range, nautical miles | 263.1 | 262.5 |
| Maximum altitude, nautical miles | 101.2 | 102.8 |
| Maximum exit dynamic pressure, lb/sq ft | 586.0 | 605.5 |

Table 8-4

Comparison of Flight Parameters for MR-3 and MR-4 Spacecraft (Cont.)

| Parameter | MR-3 Flight | MR-4 Flight |
|---|---|---|
| Maximum exit longitudinal load factor, g units | 6.3 | 6.3 |
| Maximum re-entry longitudinal load factor, g units | 11.0 | 11.1 |
| Period of weightlessness, min:sec | 5:04 | 5:00 |
| Earth-fixed velocity, at cutoff, ft/sec | 6,414 | 6,618 |
| Space-fixed velocity, at cutoff, ft/sec | 7,388 | 7,580 |

## 8.4 OPERATIONAL CHANGES RESULTING FROM FLIGHT TESTING

The new safety and reliability requirements imposed by a manned payload caused many changes in the operational launch procedures. These changes consisted mainly of checkout instructions, flight safety review board actions, instrumentation, and launch control. The general operation and organization of these factors have been described in Section 7. The design modifications resulting from the flight tests are described in paragraph 4.8.2.

During the flight program, the above procedures and operations were modified or changed as further knowledge of the MERCURY-REDSTONE launch vehicle was obtained. MR-1 demonstrated the need for compliance to careful preparation and use of special parts. The launch failure resulted in changes to assure vehicle grounding both through the added ground strap and adjustment of the electrical plug clamp.

MR-2's tank distortion was due to improper securing of the tarpaulin during air transport, a matter easily prevented on the next three vehicles.

A countdown change was made between MR-3 and MR-4 to prevent poor weather from causing a costly and hazardous condition to develop. The change involved moving the 60-minute, built-in hold from T-120 to T-180 minutes. This permitted a recheck of weather conditions and a longer hold, if necessary, before LOX loading. If the weather conditions were good and had a 90 percent chance of remaining favorable, then LOX loading would proceed.

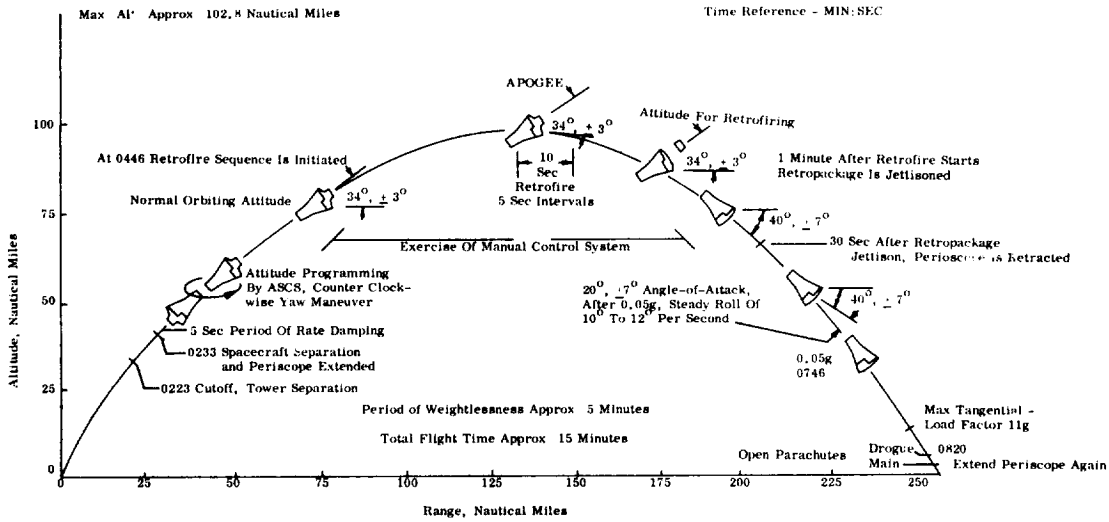



Figure 8-10. Flight Profile for MR-4

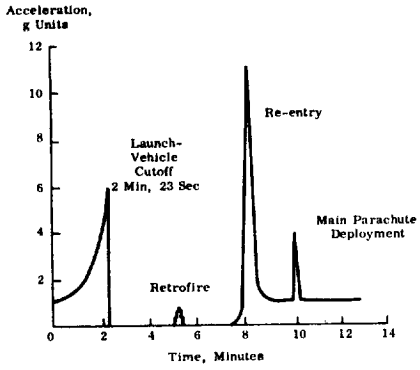



Figure 8-11. Acceleration Time History for MR-4 Flight

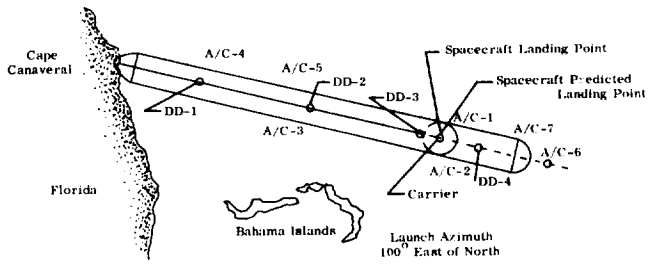



Figure 8-12. Chart of Recovery Operations

Examinations of the launch schedule and vehicle preparations, as described above, improved both crew safety and vehicle reliability. They contributed to the success of the MERCURY-REDSTONE Program and should serve as guidelines for future space efforts.

# SECTION 9

# CONTRIBUTIONS TO MANNED LAUNCH VEHICLES

## 9.1 INTRODUCTION

The preceding sections of this report have, in the course of describing the development of the MERCURY-REDSTONE launch vehicle, presented many items which represent major innovations required for the first manned flight and which are still appropriate for manned systems. As stated at the beginning of the report, our major purpose was not to present a mere record of occurrences, but to identify and highlight the lessons to be learned from a review of the complete program (both its failures and successes) which would be of value to the development of future manned launch vehicles. It is to this purpose that Section 9 is addressed. The contributions that the MERCURY-REDSTONE Program made to manned launch vehicle development are discussed under four main categories: man-rating, design, testing, and operations.

## 9.2 MAN-RATING

### 9.2.1 GENERAL

In regard to man-rating, there are a few remarks which, while not specifically related to the design of the booster, do have an important impact on any manned project. They are concerned with the question, "When is a vehicle man-rated?" In the original program schedule, the third flight of the series and those following were to be manned. This was predicated, however, on successful completion of the first two flights. While this may seem to be quite an early introduction of man, it should be noted that over 60 unmanned REDSTONE missiles had flown in other military and space research programs prior to that flight. In addition, experimental rocket aircraft had included man with the first flight of the prototype. Since, in future launch vehicles of the SATURN class, it is quite impractical to consider launching 60 boosters prior to the introduction of man, it is vital that the first manned flight take place as early as possible in the development program. In general, many groups of planners have sought the answer to this question in terms of numerical values of reliability and confidence level; however, such criteria inevitably lead to requirements for an economically unfeasible number of unmanned flights. The MERCURY-REDSTONE project team also made such analyses. However, manned flight was not approved until the launch vehicle

had demonstrated, in actual flight, its capability to perform all required functions properly. This latter criteria resulted in the manned flight being delayed until the fifth launch attempt, rather than the third, because of failures occurring in two earlier launches (MR-1 and MR-2). Delaying the introduction of man because of these failures did not result in a lengthy delay in the program and is probably justified on the basis of the qualitative increase in confidence achieved with the additional launches and the relatively small increment in time and cost incurred.

In summary then, it would appear that it is qualitative, not quantitative confidence, that determines when a launch vehicle is ready for manned flight. In support of this argument is the fact of the admittedly low quantitative confidence level which must have been associated with including a man on the first rocket aircraft flights. The MERCURY-REDSTONE was able to satisfy this criteria within reasonable constraints of time and cost; however, the flight program history clearly indicates a need for comprehensive analysis of flight schedules, including the introduction of man, with failure contingencies taken into account. As launch vehicles approach and perhaps exceed the cost of a SATURN V, it becomes imperative to determine well in advance of the first flight, what action can be taken to reduce the requirement for additional launches, prior to manned flight, in the event of a booster failure. Future programs will be efficient and timely only if we resolve a means for obtaining this intrinsic, qualitative confidence level without resorting to an additional unmanned launch each time a failure occurs. A thorough understanding of failure effects through ground testing and analytical studies is but one of the means to achieve that goal. Other items include flight safety (abort) systems to accomodate failures and detailed quality assurance programs such as were developed for MERCURY-REDSTONE.

When is a launch vehicle man-rated? When its developers have a high, but qualitative confidence that it will perform all of its functions properly and, in the improbable event of an inflight failure, safety of the crew will be assured with an abort sensing and implementation system. Ultimately, this confidence will be achieved, as with rocket aircraft presently, prior to the first full scale launch attempt.

The MERCURY-REDSTONE was the first man-rated rocket launch vehicle. There existed the unique opportunity and responsibility to investigate and provide both vehicle reliability and crew safety. Although crew safety is highly dependent on vehicle reliability, the term, crew safety, is used here to distinguish those elements of the vehicle design and operations that enhanced the astronaut's probability of a successful

recovery in the event of a failure. MERCURY-REDSTONE's contribution to these aspects of man-rating are described in the following paragraphs.

### 9.2.2 CREW SAFETY

The greatest single item added to the MERCURY-REDSTONE, which improved crew safety, was the automatic inflight abort sensing system. Automatic abort systems have also been used on the MERCURY-ATLAS. A combination of automatic and manual systems is planned for the SATURN.

In determining which parameters the abort sensing system should monitor in order to identify vehicle failures as rapidly and safely as possible, the MERCURY-REDSTONE designers faced perplexing alternatives. As the number of parameters increased, the probability of correctly identifying the cause of a failure also increased, and, in addition, the time between the first failure indication and vehicle destruction would increase, permitting more time for safe astronaut ejection. However, as a consequence of monitoring more parameters, the sensing system complexity also increases, thereby increasing the probability of its failure which could lead either to a falsely aborted mission or an astronaut fatality.

The design team elected to monitor as few parameters as possible to reduce the probability of a false abort and develop a simple system of high reliability. The reduced time between the first failure indication and vehicle destruction was accomodated by an automatic abort implementation system. Since all vehicle component or subsystem failures which may affect the mission completion or astronaut safety eventually lead to measurable changes in vehicle performance, those performance parameters were selected which would give the earliest indication of a failure, coupled with engine chamber pressure and electric power as two subsystems whose performance affected or was affected by a majority of the other vehicle subsystems.

The selection of abort sensing parameters and the establishment of their limits remains as one of the major problems confronting the designers of manned launch vehicles. The criteria developed by the MERCURY-REDSTONE team and the specific parameters they selected have turned out to be of major value and guidance to other launch vehicle programs such as ATLAS and SATURN. The inter-relationship of the abort parameters monitored and the mode of abort (manual or automatic) was also recognized at this early date, increasing the validity of the design which was eventually employed on the MERCURY-REDSTONE launch vehicle.

Since the abort system was totally new at the time of the MERCURY-REDSTONE design, many guidelines were established. The abort system had to be tailored to the vehicle, utilize existing hardware, if possible, and sense only those parameters that were easily and reliably measured commensurate with the probable failure modes. Reliability of the system was stressed in hardware selection, test, and modes of operation. Additional details of the first abort system are given in Section 5.

It is important to note that an automatic system was chosen because it was felt the astronaut could not respond quickly enough to the emergency conditions possible with the REDSTONE booster. Only the GEMINI manual abort system deviates from this basic criterion due to the GEMINI's propellant combination which has a low probability of explosion.

The automatic inflight abort sensing system also established basic ground rules for abort sensing parameters and sensors. Three basic abort parameters recognized as essential for crew safety by each manned launch vehicle project are propellant pressure, vehicle attitude rates of change, and electrical voltage (power). The MERCURY-REDSTONE design recognized that these three parameters provided monitoring of the effects of nearly all possible component and system failures. To these were added other abort parameters designed to monitor specific failure modes.

The sensors used to measure the abort parameters were to have both positive and negative redundancy; that is, the system had to be designed to assure an abort when an abort was required, and yet also assure the improbability of a false abort. Use of redundant sensors and redundant parameters gave this assurance to MERCURY-REDSTONE and MERCURY-ATLAS. This same philosophy is being applied to the GEMINI and SATURN.

The automatic inflight abort sensing system sent a signal to the capsule which activated the engine shutdown, capsule separation, and abort tower ignition systems. This sequencing could also be initiated by the astronaut, the launch director, and the MERCURY Control Center (see paragraph 5.2). To assure astronaut and range safety, the abort command inputs were armed at various times in the countdown and flight. Similar initiators of the abort signal and similar sequencing of their abort signal input are also features of all other manned launch vehicles.

### 9.2.3 VEHICLE RELIABILITY

The abort sensing system described above provided crew safety in the event of a hazardous failure. However, a catastrophic failure never occurred with the MERCURY-REDSTONE, thus indicating the successful efforts of man-rating the basic vehicle systems to provide a reliable booster flight.

The high quality of the design, manufacture, test, and checkout of the vehicle contributed to the near-perfect reliability of the MERCURY-REDSTONE. Achieving this level of quality, however, was not based on normal levels of effort. Rather, better performance from each individual in the booster program was gained through a highly motivating MERCURY Awareness Program.

This program used publicity, awards, and symbols to emphasize the importance of the individual contributor in achieving reliability. MERCURY stamps placed on MERCURY-REDSTONE documents and manned vehicle hardware continuously called attention to the fact that the astronauts' lives depended on high reliability. This program proved its effectiveness and has been duplicated in all other manned launch vehicle and payload programs.

## 9.3 DESIGN

### 9.3.1 GENERAL

The changes and modifications made to the tactical missile contributed significantly to man-rating the MERCURY-REDSTONE and to the development of methods for designing future manned launch vehicles. The following changes and their effect on the man-rated MERCURY-REDSTONE are presented as they apply to the major vehicle systems. This examination of the resulting systems and the reasons for their design thus leads to guidelines for future manned vehicle design.

### 9.3.2 PROPULSION

The first major decision regarding the propulsion system was changing to the A-7 engine at the beginning of the program to avoid a change midway through the manned vehicle development. This avoided confusion and the resulting human errors by eliminating change orders, hardware substitution, and procedural revisions.

The propellant prevalves isolated the propellant tanks from the engine system prior to launch and served no function once the engines were started. Since they could fail-closed during burning and thus initiate a false shutdown and abort, they created an unnecessary hazard. The ATLAS, TITAN, and SATURN engine systems for manned payloads have also deleted the prevalves from flight use.

Propellant explosive and toxic properties must be considered in manned launch vehicle design. The MERCURY-REDSTONE used ethyl alcohol and LOX. This combination was well known to designers and fuel handlers and thus presented no new problems. The toxicity of Hydine, which was used on the JUPITER-C, was considered unsafe for the astronaut in the event of a pad abort or a prelaunch emergency egress.

Manned flights present the problem of longer than usual holds to make sure everything is A-Okay. Long holds, however, mean a greater chilldown of the LOX lines and the total engine system. This can result in hazardous freezeups. MERCURY-REDSTONE brought this problem to the designers' attention and required fuel line bubbling, extra instrument insulation, and heater jackets for the chamber pressure sensor lines. These system features are also being used on SATURN.

Long holds also required an accurate LOX fill and "topping" system to assure meeting flight requirements. Special sensors and a computer were added to the propellant loading system.

Leakage of propellants into the engine bay could cause an accumulation of an explosive mixture. To minimize this danger the area was purged with nitrogen prior to liftoff and new seal materials were used in the hydrogen peroxide system. This safety requirement has also been imposed upon the SATURN.

### 9.3.3 STRUCTURES

Although the basic REDSTONE in the JUPITER-C configuration was used, a new aft section was necessary to provide the compartment space necessary for the guidance, control, and communication systems. The design of this section followed a design rule established then by MSFC which has been used on the SATURN. The rule states "the structure shall be self-supporting under all expected loads without internal pressure stabilization." To obtain maximum performance with safety, the tank walls varied in thickness consistent with the 1.35 factor of safety and the anticipated loads.

Prior to MERCURY-REDSTONE, the payload-vehicle interface was the dual responsibility of both prime contractors. However, to assure a safe separation and to place single responsibility for the separation on one agency and contractor, the MERCURY-REDSTONE's separation plane was totally contained within the adapter section, and the capsule contractor was given responsibility for this section. The vehicle-adapter mechanical interface then became a simple flange and bolt circle.

### 9.3.4 GUIDANCE AND CONTROL

Manned flight required the guidance to be simple and reliable; therefore, MERCURY-REDSTONE's guidance was a well-tested autopilot. During first stage burning, the SATURN also uses a simple autopilot. This design rule enhances crew safety in the relatively hazardous pad and maximum dynamic pressure regions of flight.

### 9.3.5 DESTRUCT SYSTEM AND RANGE SAFETY

The range safety fuel dispersion (destruct) system was modified by the addition of a destruct delay. This time delay would have permitted abort of the capsule to a safe distance from the booster before destruct explosion. The delay has been incorporated as a safety feature on all manned vehicles since MERCURY-REDSTONE. The MERCURY-REDSTONE also established the need for examination of launch trajectories and guidance accuracy versus range safety boundaries. The destruct delay caused the range safety limits to be proportionately narrowed, but the amount of narrowing was a function of the vehicle and its modes of failure. Hence manned launch vehicles require coordination between design and range safety requirements to attain maximum flexibility during launch.

### 9.3.6 DESIGN CRITERIA

In addition to the specific system design guides, several general design criteria were established during the MERCURY-REDSTONE development. These included the overall design factor of safety of 1.35 and the yield factor of 1.1.

## 9.4 TESTING

### 9.4.1 GROUND TESTING

The test program established for the six boosters used in the MERCURY-REDSTONE Program is described in Section 6 of this report. The MERCURY-REDSTONE

experienced the first application on a man-rated vehicle of the pyramidal testing philosophy, whereby components, subsystems, and then the entire vehicle are functionally checked. This type of testing verified proper operation of all hardware within the vehicle. As part of the prelaunch procedures and checkouts, each of the MERCURY-REDSTONE boosters were scheduled for static firing tests to insure satisfactory performance and reliability under rated thrust conditions. Due to the high degree of reliability under rated thrust conditions. Due to the high degree of reliability necessary for a man carrying vehicle, actual launch and flight conditions were simulated as closely as possible. A total of 32 static tests were conducted on the MERCURY and its test boosters with an accumulated time of over 2,230 seconds.

### 9.4.2 FLIGHT TESTING

The MERCURY-REDSTONE flight program developed the first man-rated space systems and accomplished the initial objective which was to gain space flight familiarization. The flights and the accomplishments of each toward the ultimate goal of space travel are covered in Section 8 of this report. A particularly significant contribution of the MERCURY-REDSTONE Program to Manned Launch Vehicle development was that the spacecraft was the first to experience the environment and requirements of space flight. Of equal importance to the experience of the astronauts was the invaluable training of the ground crew in the preparation, launching, and the recovery of the first two manned spacecrafts.

## 9.5 OPERATIONS

As a result of the MERCURY-REDSTONE checkout and launch operations, a number of salient considerations evolved which should be translated into future programs concerned with the launch of manned vehicles. The major considerations are listed as follows:

- Facility requirements must be comprehensively planned at the very inception of a program. Facilities and ground support equipment require as much, and sometimes more lead time than the development period of the first vehicle.
- On-the-pad emergency egress procedures are mandatory in manned space vehicle operations, and they must be considered in the earliest design phase of the complex and space vehicle to provide an optimum system.
- Integration of launch operations under one control point is essential to assure that a feasible, coordinated countdown of reasonable duration will result.

Experience indicated that some degree of automation will help to reduce the countdown period to an acceptable length.

- Serious consideration should be given to improving the reliability of obtaining, presenting, and digesting inflight information.
- Design of the space vehicle should consider test and launch operation requirements at the launch site. Design compatibility should be emphasized in the area of GSE, communications systems, ordnance requirements, emergency conditions, and interface considerations.
- Realistic scheduling is essential throughout a program but should be especially emphasized at the launch site where numerous supporting organizations must participate. Test schedules at the launch site should be coordinated by one central point to assure that precedence, priority, conflicting checkout functions, and other AMR programs are properly coordinated and controlled.
- The complexity of manned launch vehicles and the launch operations dictates that a single point of entry for range support is necessary. This procedure will assure that all NASA problems are coordinated within NASA to prevent conflicting or confusing information from reaching range or contractor personnel.
- Weather restrictions on launch operations must be reduced if critical schedules, such as launch windows, are to be met on an operational basis. Vehicle design should consider this factor in terms of allowable ground and upper-air winds. A study should be initiated to provide a method of optical coverage through the maximum dynamic pressure region which is independent of ground weather conditions.

## 9.6 CONCLUSION

Throughout this section the phrase " also used in all other manned launch vehicle programs" has been repeated many times. The numerous repetitions indicate the many manned space flight guidelines for future programs which were established by the MERCURY-REDSTONE Program. MERCURY-REDSTONE's opportunity to take the first steps into space has proved to be the making of a solid foundation for manned space travel.

SECTION 10

REFERENCES

This section presents a listing of technical reports and documents related to the MERCURY-REDSTONE Program. The MSFC documents are presented in the sequential order of the launch vehicle flights. For each flight the booster was selected on a basis of highest acceptable test performance; consequently, only flight numbers MR-1 and MR-2 utilized identical booster numbers, MR-1 and MR-2. At the time of selection of a booster for flight MR-1A, booster Number MR-3, had the highest test performance record. The fourth flight, MR-BD, utilized booster MR-5. Boosters MR-4 and MR-6 were not launched. Manned flights MR-3 and MR-4 utilized boosters MR-7 and MR-8, respectively.

By listing the MSFC prepared documents in accordance with the flight numbers, booster MR-3 information is located under MR-1A, booster MR-5 under MR-BD, and MR-7 and MR-9 under flights MR-3 and MR-4, respectively.


GENERAL

| | |
|---|---|
| AOMC CR-SS-60-6 | Satellite and Space Program Progress Report for NASA, 6 July 1960 (C) (AOMC). |
| ARS 2238-61 | Hammack, Jerome B., Herberlig, Jack C., The MERCURY-REDSTONE Program, 9-15 October 1961 (American Rocket Society). |

CHRYSLER CORPORATION MISSILE DIVISION

| | |
|---|---|
| | MERCURY-REDSTONE Reliability Test Program (CCMD). |
| Chrysler ME-M5 | Sommer, D., Vibration Test of the Steam Generator Elbow of the MERCURY-REDSTONE Engine, (CCMD). |
| Chrysler GLC-R-5 | Upton, G.S., MERCURY-REDSTONE Aft Section Test Report, October 1960 (Ground Tests) (CCMD). |

| | |
|---|---|
| Chrysler GLC-M-29 | DeBaker, J. L., Final Report for Humidity Test of MRT-1 Aft Section, 15 January 1961 (Ground Tests) (CCMD). |
| Chrysler SL-M56 | Perry, D.G., Combined Vibration and Temperature Environmental Evaluation Tests on the REDSTONE Tail Unit for MERCURY-REDSTONE Missiles, 1 April 1960 (CCMD). |
| Chrysler SL-M59 | Fama, N., and Suddath, J., Structural Reliability Testing of MERCURY-REDSTONE Thrust Unit Reports I and II, 15 April 1960 (CCMD). |
| Chrysler DSD-TM-12-60 | Sorce, Peter S., Van Camp, L., Stevens, R. E., REDSTONE Missile Malfunction Study (MERCURY-REDSTONE Program), 15 June 1960. (S) (CCMD). |
| Chrysler ML-M134 | Schayer, D. E., Combined Vibration and Temperature Environmental Tests of Mechanical Components for MERCURY-REDSTONE Missiles, 26 April 1960 (CCMD). |
| Chrysler ML-M135 | Torigian, R. M., Reliability Test of the RE 7112 a REDSTONE A-7-1 Rocket Engine, 14 April 1960 (CCMD). |

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

| | |
|---|---|
| NASA Conference | Results of the First U.S. Manned Suborbital Space Flight, 6 June 1961 (NASA).<br><br>Results of the Second U.S. Manned Suborbital Space Flight, 21 July 1961 (NASA).<br><br>Abort System Experience and Application to the Design of Advanced Crew Safety Systems (Manned Space Center - NASA). |
| MSFC MHR-2 | MERCURY-REDSTONE Chronology to December 31, 1961 May 1961 (Historical Office). |
| MTP-M-S&M-TSR-60-1 | Barraza, R.M., Glover, J.C., MERCURY Booster Recovery, 30 November 1960. |
| DLMT-TN-28-60 | Hildebrand, Arnold G., Evaluation of Flotation and Drop Tests MERCURY-REDSTONE Booster, 25 March 1960 |

| | |
|---|---|
| MTP-M-LOD-DR 60-3 | Spencer, Clayton M., MERCURY-REDSTONE Thrust Unit Water Recovery, 26 October 1960. |
| | Humphrey, John, and Bertram, Emil, Preliminary MERCURY-REDSTONE Booster Recovery Operations at Atlantic Missile Range, 20 May 1960. |
| NASA SP-45 | Kuettner, J.P., Bertram, E.P., MERCURY Project Summary, MERCURY-REDSTONE Launch Development and Performance 1963 (USA). |
| | Kuettner, J.P., Bertram, E.P., The Manned Rocket Vehicle MERCURY-REDSTONE, Proceedings of the Twelfth International Astronautical Congress, 1962 (USA). |
| DG-TR-7-59 | Brandner, F.W., Proposal for MERCURY-REDSTONE Automatic In-flight Abort Sensing System, 5 June 1959 (Technical Scientific Staff, G&C Lab). |
| LOD Brochure | FREEDOM 7, The First United States Manned Space Flight, Undated MR-3, (LOD - BROCHURE). |
| MSFC DOD - PR | Progress Report Launch Operations Directorate, 13 January 1961 - 12 February 1961, 23 February 1961 (C) (LOD). |
| MSFC MTP-AERO-61-9 | Leonard, E.L. Revised Range Safety Data for the MERCURY-REDSTONE Project, 17 February 1961 (C) (AERO). |
| MSFC TPR-M-60-12 | Leonard, N.T., MERCURY-REDSTONE Monthly Status Report, December 1960 (C) (MPO) |
| MSFC STR-M-60-1 | MERCURY-REDSTONE Monthly Status Report, January 1961 (MPO). |
| MSFC STR-M-61-4 | MERCURY-REDSTONE Monthly Status Report, February 1961 (C) (S&MD). |
| MSFC STR-M-61-6 | MERCURY-REDSTONE Monthly Status Report, March 1961 (C) )S&MD). |
| MSFC MTP-LOD-62-5 | Bertram, E.P., Dutton, R.E., Final Report MERCURY-REDSTONE Project Launch Operations, 28 May 1962 (LOD). |

MSFC MTP-AERO-61-69

Clarke, W.G., Preliminary Evaluation of MERCURY-REDSTONE Launch MR-4, 22 August 1961 (C) (AERO).

MSFC MTP-AERO-61-74

Smith, J.W., Atmospheric Environment for the Flight of MERCURY-REDSTONE MR-4, 28 September 1961 (IUO) (AERO).

MSFC MTP-AERO-61-76

Ledford, Harold, Actual Trajectory of MERCURY-REDSTONE Flight Test MR-4, 22 September 1961 (C) (AERO).

MSFC MTP-P&VE-P-61-20

Riquelmy, J.R., King, N.W., Montgomery, J.L., MERCURY-REDSTONE MR-4 Flight and Evaluation of Propulsion Unit and Associated Systems, 9 November 1961 (C) (P&VE).

MSFC MTP-LOD-OIR-61-23.1

Index and Test Results Part I of the Firing Test Report MERCURY-REDSTONE Vehicle MR-4, 15 August 1961 (C) (LOD).

MSFC MTP-LOD-ED-61-23.2b

Hinds, Noble F., Instrumentation Operations Analysis Part IIb at the Firing Test Report MERCURY-REDSTONE MR-4, 24 August 1961 (C) (LOD).

MSFC MTP-LOD-MP-61-23.3

Heezen, Kenneth F., Hill, Lawrence F., Firing Site Weight Report Part III of the Firing Test Report MERCURY-REDSTONE MR-4, 2 August 1961 (C) (LOD).

| | |
|---|---|
| MTP-M-LOD-DR 60-3 | Spencer, Clayton M., MERCURY-REDSTONE Thrust Unit Water Recovery, 26 October 1960. |
| | Humphrey, John, and Bertram, Emil, Preliminary MERCURY-REDSTONE Booster Recovery Operations at Atlantic Missile Range, 20 May 1960. |
| NASA SP-45 | Kuettner, J.P., Bertram, E.P., MERCURY Project Summary, MERCURY-REDSTONE Launch Development and Performance 1963 (USA). |
| | Kuettner, J.P., Bertram, E.P., The Manned Rocket Vehicle MERCURY-REDSTONE, Proceedings of the Twelfth International Astronautical Congress, 1962 (USA). |
| DG-TR-7-59 | Brandner, F.W., Proposal for MERCURY-REDSTONE Automatic In-flight Abort Sensing System, 5 June 1959 (Technical Scientific Staff, G&C Lab). |
| LOD Brochure | FREEDOM 7, The First United States Manned Space Flight, Undated MR-3, (LOD - BROCHURE). |
| MSFC DOD - PR | Progress Report Launch Operations Directorate, 13 January 1961 - 12 February 1961, 23 February 1961 (C) (LOD). |
| MSFC MTP-AERO-61-9 | Leonard, E.L. Revised Range Safety Data for the MERCURY-REDSTONE Project, 17 February 1961 (C) (AERO). |
| MSFC TPR-M-60-12 | Leonard, N.T., MERCURY-REDSTONE Monthly Status Report, December 1960 (C) (MPO) |
| MSFC STR-M-60-1 | MERCURY-REDSTONE Monthly Status Report, January 1961 (MPO). |
| MSFC STR-M-61-4 | MERCURY-REDSTONE Monthly Status Report, February 1961 (C) (S&MD). |
| MSFC STR-M-61-6 | MERCURY-REDSTONE Monthly Status Report, March 1961 (C) )S&MD). |
| MSFC MTP-LOD-62-5 | Bertram, E.P., Dutton, R.E., Final Report MERCURY-REDSTONE Project Launch Operations, 28 May 1962 (LOD). |

MSFC MTP-M-QUAL-61-3 — Conaway, J.D., MERCURY-REDSTONE System Reliability Test Report, Rate Switches, 13 April 1961 (IUO) (QUAL).

MSFC MTP-M-QUAL-60-10 — Coleman, R.H., Reliability Test Report Altitude Error Sensor MERCURY-REDSTONE System, 30 November 1960 (IUO).

MSFC MTP-M-QUAL-60-11 — Coleman, R.H., MERCURY-REDSTONE System Reliability Test Report for Control Voltage Failure Detector, 30 November 1960 (IUO) (QUAL).

MSFC MTP-M-RP-61-6 — Dalton, Charles, Mission Reliability of Booster Flight for MERCURY-REDSTONE, 24 February 1961 (IUO) (RPD).

FLIGHT REPORTS

MERCURY-REDSTONE Flight, MR-1

MSFC MNM-M-AERO-2-60 — Lisle, Ben J., Teague, Roger, Project MERCURY-REDSTONE: Final Standard Trajectory for MR-1, 1 August 1960 (C) (NASA).

MSFC MM-M-SAR-2.1-60 — Davis, C.H., Final Alignment Report of Missile MR-1, 1 August 1960 (MSFC).

MSFC TIS — Jones, Charles B., Technical Information Summary Concerning MERCURY-REDSTONE Mission MR-1, 15 October 1960 (C) (G and CD).

MSFC MTP-M-TEST-61-10 — Earnest, Hugh S., Static Firing of MERCURY-REDSTONE No. 1 Test Nos. 347, 348, and 349, April 1961 (IUO), MR-1 (TEST).

MSFC MTP-M-S&M-P-61-1 — Riguelmy, J.R., MERCURY-REDSTONE MR-1 Flight Analysis of Propulsion Unit and Associated Systems, 5 January 1961 (C) (S&MD).

MSFC MTP-LOD-DIR-60-49.1 — Index and Test Results Part I of the Firing Test Report MERCURY-REDSTONE Vehicle MR-1, 27 December 1960 (C) (LOD).

MSFC MTP-LOD-ED-60-49.2b — Hinds, Noble F., Instrumentation Operation Analysis Part IIb of the Firing Test Report MERCURY-REDSTONE MR-1, Undated (LOD)

MSFC MTP-LOD-MP-60-49.3 — Martin, Thomas E., Firing Site Weight Report Part III of the Firing Test Report MERCURY-REDSTONE MR-1, 6 January 1961 (C) (LOD).

MSFC MM-M-SAR-2.3-60 — Guidance and Control System Checkout MR-1, 3 August 1960 (MSFC).

MSFC MM-M-SAR-2.5-60 — Covington, C.H., Pincham, A.G., Measuring System Analysis MR-1, 4 August 1960 (MSFC).

MSFC MM-M-SAR-2.6-60 — Fisher, A.E., Pickard, M.F., Final Mechanical Analysis of MR-1 Thrust Unit, 5 August 1960 (MSFC).

MSFC MTP-LOD-EF-TR-49.2a-60 — Gwinn, Ralph T., Consolidated Instrumentation Plan Part IIa of the Firing Test Report MERCURY-REDSTONE MR-1, 19 November 1961 (S) (LOD).

MSFC M-LOD-G-TR-49.4-60 — Master Operational Schedule Part IV of the Firing Test Report MERCURY-REDSTONE Spacecraft MR-1, 15 November 1960 (OUD) (LOD).

MSFC MM-M-SAR-2-60 — Final Acceptance Test Report MR-1, 12 September 1960 (SAR).

MSFC MM-M-SAR-2.4-60 — Bryan, F.G., Test Conductor's Report MR-1, 1 August 1960 (SAR).

MSFC MTP-M-QUAL-61-7 — Post-Firing Electrical Analysis MR-1 Thrust Unit, 28 February 1961 (IUO) (QUAL).

MERCURY-REDSTONE Flight MR-1A

MSFC TPR-M-61-1 — Clarke, W.G., Preliminary Evaluation of MERCURY-REDSTONE Launch MR-1A, 13 January 1961 (C) (AERO).

MSFC STR-M-61-3 — Ledford, Harold, Actual Trajectory of MERCURY-REDSTONE Flight Test MR-1A, 1 March 1961 (C) (AERO).

MSFC MTP-AERO-61-10 — Smith, J.W., Atmospheric Environment for MERCURY REDSTONE-1A Vehicle Flight, 24 February 1961 (IUO) (AERO).

MSFC MTP-M-S&M-P-61-5 — Riquelmy, J.R., King, M.W., McDonald, N.G., MERCURY-REDSTONE MR-1A Flight Evaluation of Propulsion Unit and Associated Systems, 24 February 1961 (C) (S&MD).

MSFC MTP-LOD-DIR-61-61.1 — Index and Test Results Part I of the Firing Test Report MERCURY-REDSTONE Vehicle MR-1A, 16 January 1961 (C) (LOD).

MSFC MTP-M-QD-60-8 — Final Acceptance Test Report MR-3, 15 December 1960 (IUO) (QUA).

MSFC MTP-M-QD-60-8.1 — Davis, C.H., Final Alignment Report MR-3, 1 December 1960 (IUO) (QUAL).

MSFC MTP-LOD-ED-60-61.2b — Hinds, Noble F., Instrumentation Operation Analysis Part IIb of the Firing Test Report MERCURY-REDSTONE MR-1A, 2 February 1961 (C) (LOD).

MSFC MTP-LOD-MP-60-61.3 — Martin, Thomas E., Heezen, Kenneth F., Firing Site Weight Report Part III of the Firing Test Report MERCURY-REDSTONE MR-1A, 2 February 1961 (C) (LOD).

MSFC MTP-LOD-EF-60-61.2a — Gwinn, Ralph T., Consolidated Instrumentation Plan Part IIa of the Firing Test Report MERCURY-REDSTONE MR-1A, 16 December 1960 (S) )LOD).

MERCURY-REDSTONE Flight, MR-2

MSFC TPR-M-60-1 — Jones, Charles B., Technical Information Summary Concerning MERCURY-REDSTONE Mission MR-2, 20 January 1961 (C) (G&CD).

MSFC MTP-M-SAR-60-3.1 — Davis, C.H., Final Alignment Report MR-2, 10 October 1960 (SA&RD).

MSFC STR-M-61-2 — Clarke, W.G., Preliminary Evaluation of MERCURY-REDSTONE Launch MR-2, 25 February 1961 (C) (AERO).

MSFC MTP-AERO-61-30 — Ledford, Harold, Actual Trajectory of MERCURY-REDSTONE Flight Test MR-2, 4 April 1961 (C) (AERO).

MSFC STR-M-61-7 — Smith, J.W., Atmospheric Environment for the Flight of MERCURY-REDSTONE 2, 25 March 1961 (AERO).

MSFC MTP-M-COMP-61-2

Fallon, Robert A., Smith, Martha E., DOVAP Flight Test Data Missile MR-2, 1 March 1961 (C) (COMP).

MSFC MTP-M-S&M-P-61-10

Riquelmy, James R., King, Merle W., MERCURY-REDSTONE MR-2 Flight Evaluation of Propulsion Unit and Associated Systems, 2 June 1961 (C) (S&MD).

MSFC MTP-LOD-OIR-61-4.1

Index and Test Results Part I of the Firing Test Report MERCURY-REDSTONE Vehicle MR-2, 20 February 1961 (C) (LOD).

MSFC MTP-LOD-EF-61-4.2a

Gwinn, Ralph T., Consolidated Instrumentation Plan Part IIa of the Firing Test Report MERCURY-REDSTONE MR-2, 9 February 1961 (S) (LOD).

MSFC MTP-LOD-ED-61-4.2b

Hinds, Noble F., Instrumentation Operation Analysis Part IIb of the Firing Test Report MERCURY-REDSTONE MR-2, 7 April 1961 (C) (LOD).

MSFC MTP-LOD-ED-61-4.3

Martin, Thomas E., Firing Site Weight Report Part III of the Firing Test Report MERCURY-REDSTONE MR-2, Undated (C) (LOD).

MERCURY-REDSTONE Booster Development Flight, MR-BD

MSFC MTP-M-COMP-61-6

Fallon, Robert A., Smith, Martha E., DOVAP Flight Test Data MERCURY-REDSTONE BD, 8 May 1961 (C) (COMP).

MSFC MTP-M-S&M-P-61-7

Riquelmy, J.R., King, M.W., McDonald, N.G., MERCURY-REDSTONE MR-BD Flight Evaluation of Propulsion Unit and Associated Systems, 3 August 1961 (C) (S&MD).

MSFC MTP-LOD-OIR-61-11.1

Index and Test Results Part I of the Firing Test Report MERCURY-REDSTONE Vehicle MR-BD, 7 April 1961 (C) (LOD).

MSFC MTP-LOD-ED-61-11.2b

Hinds, Noble F., Instrumentation Operations Analysis Part IIb of the Firing Test Report MERCURY-REDSTONE MR-BD, 14 April 1961 (C) (LOD).

MSFC MTP-LOD-MP-61-11.3

Heezen, Kenneth F., Firing Site Weight Report Part III of the Firing Test Report MERCURY-REDSTONE MR-BD, 17 April 1961 (C) (LOD).

MSFC MTP-LOD-EF-61-11.2a — Gwinn, Ralph T., Consolidated Instrumentation Plan Part IIa of the Firing Test Report MERCURY-REDSTONE MR-BD, 23 March 1961 (C) (LOD).

MSFC MTP-AERO-61-36 — Clarke, W.G., Preliminary Evaluation of MERCURY-REDSTONE Launch MR-BD, 19 April 1961 (C) (AERO).

MSFC MTP-AERO-61-43 — Ledford, Harold, Actual Trajectory of MERCURY-REDSTONE Flight Test MR-BD, 24 May 1961 (C) (AERO).

MSFC MTP-AERO-61-51 — Smith, J.W., Atmospheric Environment for MERCURY-REDSTONE BD Vehicle Flight, 1 May 1961 (IUO) (AERO).

MSFC MTP-M-QUAL-61-4 — Final Acceptance Test Report Thrust Unit MR-5, 21 March 1961 (IUO) (QUAL).

MSFC MTP-M-QUAL-61-4.1 — Davis, C.H., Final Alignment Report MR-5, 24 February 1961 (QUAL).

MSFC MTP-M-QUAL-61-4.2 — Lackey, M., Electrical Systems Analysis MR-5, 24 January 1961 (IUO) (QUAL).

MSFC MTP-M-QUAL-61-4.3 — Bruce, R.B., Test Conductors Report MR-5, 23 January 1961 (IUO) (QUAL).

MSFC MTP-M-QUAL-61-4.4 — Smith, A.G., Radio Frequency Systems Test Report MR-5, 26 January 1961 (IUO) (QUAL).

MSFC MTP-M-QUAL-61-4.5 — Guidance and Control System Checkout MR-5, 31 January 1961 (IUO) (QUAL).

MSFC MTP-M-QUAL-61-4.6 — Measuring Systems Analysis MR-5, 30 January 1961 (IUO) (QUAL).

MSFC MTP-M-QUAL-61-4.7 — Sarture, A.C., Final Mechanical Assembly Analysis Thrust Unit MR-5, 13 March 1961 (IUO) (QUAL).

MSFC MTP-M-QUAL-61-4.8 — Kulas, F., Final Pressure and Functional Analysis, Thrust Unit MR-5, 9 March 1961 (IUO) (QUAL).

MERCURY-REDSTONE Flight, MR-3

MSFC MPR-M-61-5 — Martin, James J., Jr., Description of MERCURY-REDSTONE Launch Vehicle for Flight No. MR-3, 21 July 1961 (S&MD).

| | |
|---|---|
| MSFC MTP-M-TEST-61-6 | Earnest, H.S., Static Firing of MERCURY-REDSTONE No. 7 Test No. 346, 7 March 1961 (MR-BD) (TEST). |
| MSFC MTP-M-COMP-61-7 | Fallon, Robert A., Smith, Martha E., DOVAP Flight Test Data MERCURY-REDSTONE 3, 26 July 1961 (C) (COMP). |
| MSFC MTP-M-QUAL-61-10 | Final Acceptance Test Report Thrust Unit, MR-7, 7 April 1961 (IUO) (QUAL). |
| MSFC MTP-M-QUAL-61-10.1 | Manning, F.T., Final Alignment Report Thrust Unit, MR-7, 3 April 1961 (IUO) (QUAL). |
| MSFC MTP-M-QUAL-61-10.2 | Electrical Systems Analysis Thrust Unit, MR-7, 29 March 1961 (IUO) (QUAL). |
| MSFC MTP-M-QUAL-61-10.3 | Lackey, M., Test Conductor's Report Thrust Unit, MR-7, 23 March 1961 (IUO) (QUAL). |
| MSFC MTP-M-QUAL-61-10.4 | Norton, C.M., Radio Frequency Systems Test Report Thrust Unit MR-7, 20 March 1961 (IUO) (QUAL). |
| MSFC MTP-M-QUAL-61-10.5 | Guidance and Control System Checkout Thrust Unit, MR-7, 24 March 1961 (IUO) (QUAL). |
| MSFC MTP-M-QUAL-61-10.6 | Instrumentation Analysis Thrust Unit MR-7, 31 March 1961 (IUO) (QUAL). |
| MSFC MTP-M-QUAL-61-10.7 | Sartore, A.C., Final Mechanical Assembly Analysis Thrust Unit MR-7, 6 April 1961 (IUO) (QUAL). |
| MSFC MTP-M-QUAL-61-10.8 | Kulas, F., Final Pressure and Functional Analysis, Thrust Unit MR-7, 30 March 1961 (IUO) (QUAL). |
| MSFC MTP-M-S&M-P-61-16 | Riquelmy, James R., King, Merle W., MERCURY-REDSTONE MR-3 Flight Evaluation of Propulsion Unit and Associated Systems, 3 August 1961 (C) (S&MD). |
| MSFC MTP-LOD-ED-61-17.2b | Hinds, Noble F., Instrumentation Operation Analysis Part IIb of the Firing Test Report MERCURY-REDSTONE MR-3, 29 June 1961 (C) (LOD). |
| MSFC MTP-LOD-MP-61-17.3 | Heezen, Kenneth F., Firing Site Weight Report Part II of the Firing Test Report MERCURY-REDSTONE MR-3, 22 May 1961 (C) (LOD). |

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| MSFC MTP-M-QD-60-8.2 | Electrical Systems Analysis MR-3, 7 December 1960 (IUO) (QUAL). |
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| MSFC MTP-M-QD-60-8.4 | Smith, A.G., Radio Frequency Systems Test Report MR-3, 1 December 1960 (IUO) (QUAL). |
| MSFC MTP-M-QD-60-8.5 | Guidance and Control System Checkout MR-3, 2 December 1960 (IUO) (QUAL). |
| MSFC MTP-M-QD-60-8.6 | Measuring System Analysis MR-3, 2 December 1960 (IUO) (QUAL). |
| MSFC MTP-M-QD-60-8.8 | Kulas, F., Final Mechanical Pressure and Functional Analysis of Missile MR-3, 5 December 1960 (IUO) (QUAL). |
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| MSFC MTP-LOD-MP-61-23.3 | Heezen, Kenneth F., Hill, Lawrence F., Firing Site Weight Report Part III of the Firing Test Report MERCURY-REDSTONE MR-4, 2 August 1961 (C) (LOD). |
| MSFC MTP-M-G&C-61-29 | Jones, Charles E., Technical Information Summary Concerning MERCURY-REDSTONE Mission MR-4, 29 June 1961 (IUO) (G&CD). |
| MSFC MTP-AERO-61-19 | Speer, F.A., Preliminary Evaluation of MERCURY-REDSTONE Launch MR-4, 8 December 1960 (C) (AERO). |

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MSFC MTP-AERO-61-74

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MSFC MTP-AERO-61-76

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MSFC MTP-P&VE-P-61-20

Riquelmy, J.R., King, N.W., Montgomery, J.L., MERCURY-REDSTONE MR-4 Flight and Evaluation of Propulsion Unit and Associated Systems, 9 November 1961 (C) (P&VE).

MSFC MTP-LOD-OIR-61-23.1

Index and Test Results Part I of the Firing Test Report MERCURY-REDSTONE Vehicle MR-4, 15 August 1961 (C) (LOD).

MSFC MTP-LOD-ED-61-23.2b

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MSFC MTP-LOD-MP-61-23.3

Heezen, Kenneth F., Hill, Lawrence F., Firing Site Weight Report Part III of the Firing Test Report MERCURY-REDSTONE MR-4, 2 August 1961 (C) (LOD).

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NASA SP-45

# MERCURY PROJECT SUMMARY

## INCLUDING RESULTS OF THE

# FOURTH MANNED ORBITAL FLIGHT

MAY 15 AND 16, 1963

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Manned Spacecraft Center
PROJECT MERCURY

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# MERCURY PROJECT SUMMARY INCLUDING RESULTS OF THE FOURTH MANNED ORBITAL FLIGHT MAY 15 AND 16, 1963




NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
PROJECT MERCURY

October 1963

Office of Scientific and Technical Information

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C.

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# ERRATA—NASA REPORT SP–45

*Page 129*—For the first five lines in left-hand column, substitute the following:

The United Kingdom also assisted in the selection of communication sites in Africa and in the South Pacific and continued to provide support in the operation and maintenance of certain communication facilities.

The Republic of Nigeria provided land near the city of Kano, assisted in the construction of the station and ground communication facilities, and provided continued support during the operational phase.

The Republic of Zanzibar provided land and assisted in the establishment of the station and ground communication facilities.

The Government of Spain provided land on Grand Canary Island and established the Instituto Nacional de Técnica Aeronáutica (INTA) as the Spanish agency to participate in the implementation and operation of this facility.

The Government of Mexico provided land and participated in the implementation of the station near Guaymas, Mexico. In a joint effort, the Mexico-United States Commission for Space Tracking Observation was formed to provide coordination for the construction and operation of this station.

In establishing stations as a joint effort with the various participating countries, every effort was made to make maximum possible use of local resources and people, to permit free access to the sites, and to establish a basis for continued cooperation throughout the program.

*Pages 369–381*— The following names were inadvertently omitted from Appendix E.

Aikenhead, Bruce A.
Armstrong, Neil
Baker, Charles
Baker, Thomas F.
Bathurst, Raymond
Bavely, James C.
Bayer, Philip J.
Berry, Lt. Col. S. L.
Brackett, Ernest W.
Breneman, G. Jean
Brockett, H. R.
Buckley, Edmond C.
Chiabotta, R. L.
Clark, Lt. Col. Raymond L.
Conger, Dean
Connor, Lt. Col. Joseph
Cox, Hiden T.
Decherd, Mary C.
Dembling, Paul G.
Dick, Louise
Donlan, Charles J.
Draim, Lt. Cmdr. John E.
Dunkleman, Dr. Lawrence
Evans, Peggy R.
Ferrando, James A.
Ferrando, Rita P.
Frutkin, Arnold W.
Gaever, A. Les
Gamble, Dr. Allen O.
Gesell, Ralph T.
Giannini, William F.
Gibbs, Col. Asa B.
Gill, Dr. Jocelyn R.
Glahn, Earl W.
Glennan, Dr. T. Keith
Goett, Dr. Harry J.
Hand, Ben R.
Haney, Paul
Hare, Linda J.
Harlan, Charles S.
Hartley, Robert M.
Hayes, Capt. Richard
Heaton, Lt. Col. Donald J.
Hemperly, John O.
Henry, Maj. Richard C.
Holmes, D. B.
Holmes, Jay
Horner, Richard E.
Hunter, Willson H.
Hyatt, Abraham
Jenkins, Thomas E.
Johnson, Clinton T.
Johnson, Harold G.
Johnson, Jennie M.
Keany, J.
Kehlet, Alan B.
Kier, Cmdr. Kenneth
Krieger, Robert L.
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Leech, Ted B.
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McGee, Bernard J.
McTigue, John
Neal, James L.
Ostrander, Maj. Gen. Donald R.
Overton, John D.
Petersen, Cdr. Forrest N.
Porter, Thomas J.
Powers, Col. John A.
Rabb, L.
Reed, Carol C.
Rice, Charles N.
Ricker, Harry H., Jr.
Roadman, Brig. Gen. Charles
Salmassy, Omar K.
Sanders, Newell D.
Schmidt, Richard A.
Seamans, Dr. Robert C.
Silverstein, Abe
Soulé, Hartley A.
Stack, John
Stelter, Laverne R.
Stockwell, Ephriam
Thompson, Carolyn B.
Thompson, Floyd L.
Truszynski, G. M.
Turner, Lt. Col. W. R.
von Braun, Wernher
Walker, Joseph
Wallace, Robert F.
White, Dr. Stanley C.
Williams, J. J.
Wilson, Charles
Wolhart, Walter O.
Wood, Clotaire
Wyatt, D. D.
Young, Col. Robert P.
Zimmerman, C. H.

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# FOREWORD

This document presents a summary of the planning, preparation, experiences, and results of Project Mercury and includes the results of the fourth United States manned orbital flight conducted on May 15 and 16, 1963, are also included. The papers are grouped into four main technical areas: The space-vehicle development, mission support development, flight operations, and mission results. The performance discussions contained in the various papers for the concluding Mercury mission form a continuation of the information previously published for the three manned orbital flights and the two manned suborbital flights. Although this document, to a limited degree, summarizes the results of the previous manned flights, the formal postflight reports published for these earlier missions should be consulted for greater detail.

The material presented in this document has been prepared in a short period of time. It reflects the close cooperation and intense efforts of the authors, the staff editors, and the printers, all of whom are to be commended for their dedicated efforts.

KENNETH S. KLEINKNECHT,
*Manager, Mercury Project.*

W. M. BLAND, JR.,
*Deputy Manager, Mercury Project.*

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# 1. PROJECT REVIEW

By WALTER C. WILLIAMS, *Deputy Director for Mission Requirements and Flight Operations, NASA Manned Spacecraft Center;* KENNETH S. KLEINKNECHT, *Manager, Mercury Project, NASA Manned Spacecraft Center;* WILLIAM M. BLAND, JR., *Deputy Manager, Mercury Project, NASA Manned Spacecraft Center; and* JAMES E. BOST, *Chief, Engineering Operations Office, Mercury Project Office, NASA Manned Spacecraft Center*

## Summary

The United States' first manned space flight project was successfully accomplished in a 4⅔ year period of dynamic activity which saw more than 2,000,000 people from many major government agencies and much of the aerospace industry combine their skills, initiative, and experience into a national effort. In this period, six manned space flights were accomplished as part of a 25-flight program. These manned space flights were accomplished with complete pilot safety and without change to the basic Mercury concepts. It was shown that man can function ably as a pilot-engineer-experimenter without undesirable reactions or deteriorations of normal body functions for periods up to 34 hours of weightless flight.

Directing this large and fast moving project required the development of a management structure and operating mode that satisfied the requirement to mold the many different entities into a workable structure. The management methods and techniques so developed are discussed. Other facets of the Mercury experience such as techniques and philosophies developed to insure well-trained flight and ground crews and correctly prepared space vehicles are discussed. Also, those technical areas of general application to aerospace activities that presented obstacles to the accomplishment of the project are briefly discussed. Emphasis is placed on the need for improved detail design guidelines and philosophy, complete and appropriate hardware qualification programs, more rigorous standards, accurate and detailed test procedures, and more responsive configuration control techniques.

## Introduction

The actual beginning of the effort that resulted in manned space flight cannot be pinpointed although it is known that the thought has been in the mind of man throughout recorded history. It was only in the last decade, however, that technology had developed to the point where man could actually transform his ideas into hardware to achieve space flight. Specific studies and tests conducted by government and industry culminating in 1958 indicated the feasibility of manned space flight. Implementation was initiated to establish a national manned space-flight project, later named Project Mercury, on October 7, 1958.

The life of Project Mercury was about 4⅔ years, from the time of its official go-ahead to the completion of the 34-hour orbital mission of Astronaut Cooper. During this period, much has been learned about man's capabilities in the space environment and his capabilities in earth-bound activities which enabled the successful accomplishment of the objectives of the Mercury Project in this relatively short period. It is the purpose of this paper to review the more significant facets of the project beginning with the objectives of the project and the guidelines which were established to govern the activity. As in any form of human endeavor, there are certain signs which serve as the outward indication of activity and progress. For the Mercury Project, these signs were the major full-scale flight tests. These tests will be reviewed with particular emphasis on schedule, the individual mission objectives, and the results from each mission. Then, the organization with which management directed the

activities of Project Mercury will be explained, particularly with respect to those internal interfaces between major segments of NASA and those external interfaces with contractors and other governmental departments. The resources expended during the project will be explained with discussions on manpower and cost. In addition, the major results of the project will be discussed as will those areas which presented severe obstacles to technical progress.

This paper is primarily a review; greater detail in many of the areas discussed can be obtained by reference to other papers in this document and to the documents listed in the bibliography.

## Objectives and Guidelines

The objectives of the Mercury Project, as stated at the time of project go-ahead, were as follows:

(1) Place a manned spacecraft in orbital flight around the earth.

(2) Investigate man's performance capabilities and his ability to function in the environment of space.

(3) Recover the man and the spacecraft safely.

After the objectives were established for the project, a number of guidelines were established to insure that the most expedient and safest approach for attainment of the objectives was followed. The basic guidelines that were established are as follows:

(1) Existing technology and off-the-shelf equipment should be used wherever practical.

(2) The simplest and most reliable approach to system design would be followed.

(3) An existing launch vehicle would be employed to place the spacecraft into orbit.

(4) A progressive and logical test program would be conducted.

More detailed requirements for the spacecraft were established as follows:

(1) The spacecraft must be fitted with a reliable launch-escape system to separate the spacecraft and its crew from the launch vehicle in case of impending failure.

(2) The pilot must be given the capability of manually controlling spacecraft attitude.

(3) The spacecraft must carry a retrorocket system capable of reliably providing the necessary impulse to bring the spacecraft out of orbit.

(4) A zero-lift body utilizing drag braking would be used for reentry.

(5) The spacecraft design must satisfy the requirements for a water landing.

It is obvious by a casual look at the spacecraft (fig. 1–1) that requirements (1), (3), and (4) were followed as evidenced by the escape tower, the retrorocket system that can be seen on the blunt end of the spacecraft, and the simple blunt-body shape without wings. Items (2) and (5) have been made apparent by the manner in which the astronaut has manually controlled the attitude of the spacecraft during orbital maneuvers, retrofire, and reentry, and by the recovery of the spacecraft and astronauts after each flight by recovery forces which included aircraft carriers and destroyers.

Basically, the equipment used in the spacecraft was derived from off-the-shelf equipment or through the direct application of existing technology, although some notable exceptions were made in order to improve reliability and flight safety. These exceptions include:

(1) An automatic blood-pressure measuring system for use in flight.

(2) Instruments for sensing the partial pressures of oxygen and carbon dioxide in the oxygen atmosphere of the cabin and suit, respectively.

Some may argue with the detailed way in which the second basic guideline of simplicity was carried out; however, this guideline was carried out to the extent possible within the volume, weight, and redundancy requirements imposed upon the overall system. The effect of the weight and volume constraints, of course, resulted in smaller and lighter equipment that could not always be packaged in an optimum way for simplicity.

Redundancy probably increased the complexity of the systems more than any other requirement. Because the spacecraft had to be qualified by space flight first without a man onboard and then because the reactions of man and his capabilities in the space environment were unknown, provisions for a completely automatic operation of the critical spacecraft functions were provided. To insure reliable operation, these automatic systems were backed up by redundant automatic systems.

The third guideline was satisfied by an adap-

tation of an existing missile, the Atlas. The modifications to this launch vehicle for the use in the Mercury Project included the addition of a means to sense automatically impending catastrophic failure of the launch vehicle and provisions to accommodate a new structure that would form the transition between the upper section of the launch vehicle and the spacecraft. Also, the pilot-safety program was initiated to insure the selection of quality components.

Application of the fourth guideline is illustrated by the major flight schedule which is discussed in the next section.

## Major Flight Schedules

### Planned Flight Test Schedule

The Mercury flight schedule that was planned early in 1959 is shown in figure 1–2. These are the major flight tests and include all those scheduled flight tests that involved rocket-propelled full-scale spacecraft, including boilerplate and production types. The planned flight test program shows 27 major launchings. There are three primary types of tests included in these, one type being the research-and-development tests, another being primarily flight-qualification of the production spacecraft, and the third being the manned orbital flight tests. In addition, the tests with the Mercury-Redstone launch vehicle provided some early ballistic flights for pilot training. Involved in the planned flight-test program were four basic types of launch vehicles, the Little Joe, the Mercury-Redstone, the Mercury-Jupiter, and the Mercury-Atlas.

Four Little Joe flights and two of the Atlas powered flights, termed Big Joe, were planned to be in the research and development category to check the validity of the basic Mercury concepts.

The qualification program was planned to use each of the four different launch vehicles. The operational concept of the qualification program provided for a progressive build-up of flight-test system complexity and flight-test conditions. It was planned that the operation of all

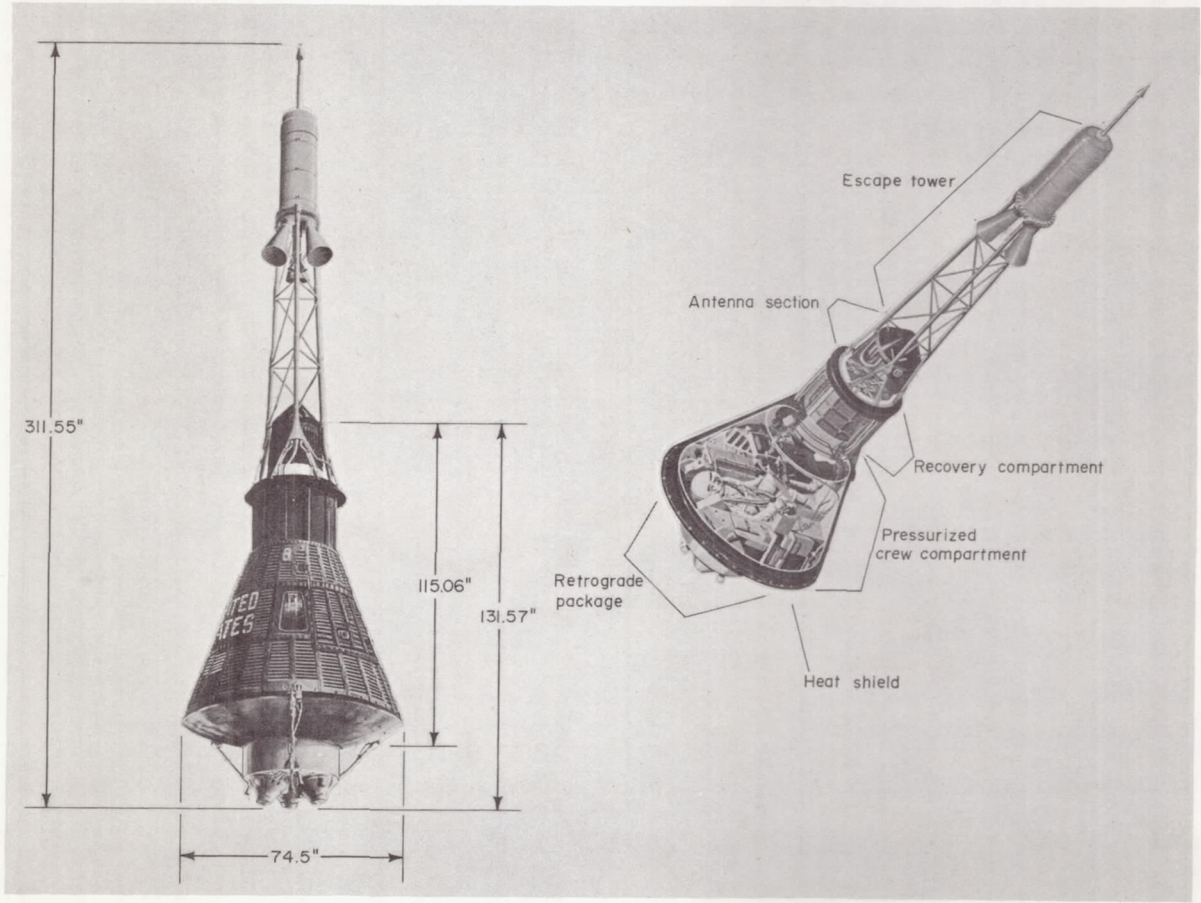



FIGURE 1–1.—General view of spacecraft.

hardware items would be proven in those environments to which they would be subject in both normal and emergency conditions associated with attainment of the planned mission conditions. One qualification flight test was planned with the use of the Little Joe launch vehicle. This test was planned to qualify the operation of the production spacecraft in a spacecraft-abort situation at the combination of dynamic pressure, Mach number, altitude, and flight-path angle that represented the most severe condition anticipated for the use of this system during an orbital launch. There were eight flight tests planned with the use of the Redstone launch vehicle. The first two were intended to be unmanned tests used to qualify the production spacecraft and to qualify the production-spacecraft launch-vehicle combination. The remaining six Mercury-Redstone flights were to be used to train and qualify Mercury astronauts for later orbital flights. Two flight tests were planned in which the Jupiter launch vehicle was to be used. The first one of these was to be made to qualify the production spacecraft for those flight conditions which produced the greatest load factor during reentry. The second Jupiter powered flight was scheduled as a backup to the first. The qualification program for the production spacecraft also included plans for three flight tests using the Atlas launch vehicle and the remainder of the flights were expected to be used for manned orbital flight if the flight qualification achieved at the time so warranted.

This flight-test plan was developed and proposed in early 1959 as a test plan that represented a completely trouble-free preparation and flight-test program. According to this schedule, the first manned orbital flight could have occurred as early as April of 1960. This flight-test schedule represents planning that was done before experience was gained in the production of spacecraft flight hardware and, particularly important, before any experience had been gained in the preparation of space flight equipment for manned flight.

The planned flight test schedule (fig. 1–2) presents some missions that are shaded. This shading indicates that these particular missions were eliminated during the course of the program because the requirement either was not necessary or was satisfied by some other means. In addition, it should be noted that the objectives of some of the other missions were altered to fit the situation as the project advanced.

### Actual Flight Test Schedules

The 25 major flight tests accomplished during the Mercury Project are shown in figure 1–3, in the order of their occurrence. Those flight-test missions which are marked with solid circles in-

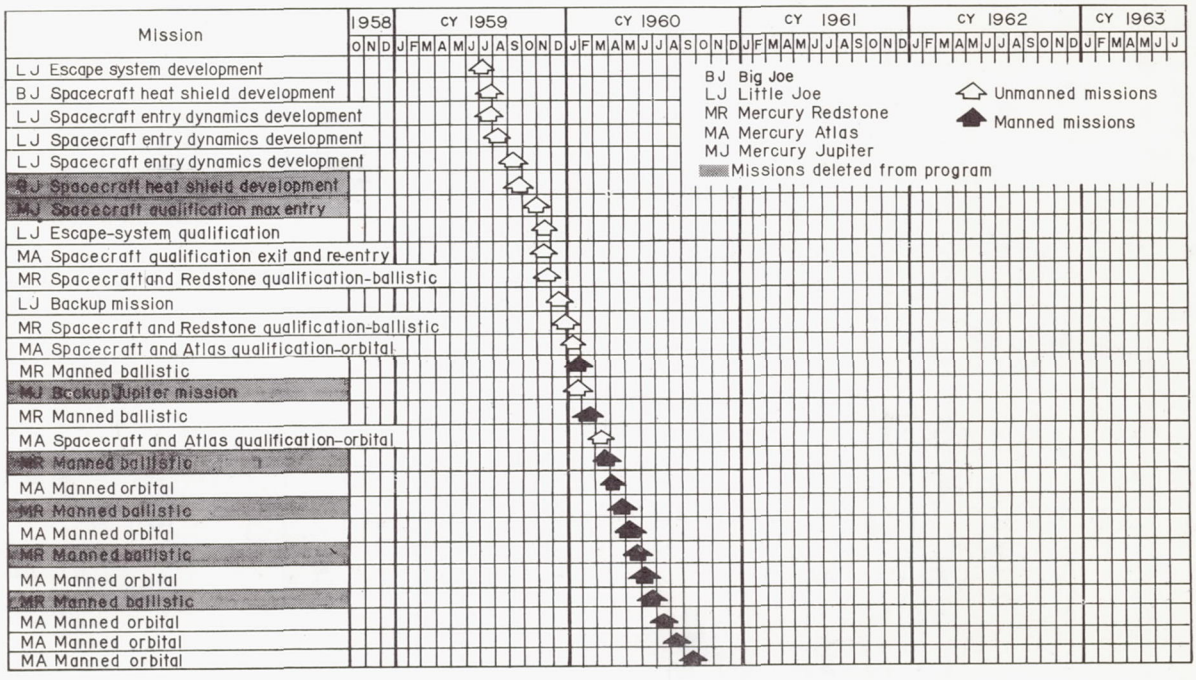



FIGURE 1–2.—Planned flight schedule as of January 1959.

dicate the missions that were added to this schedule as a result of lessons learned during some of the preceding flight tests or because of extensions to the basic mission objectives as in the case of the last two missions, MA–8 and MA–9.

*Little Joe 1.*—The flight test program was initiated with the Little Joe 1 research-and-development mission that was scheduled for July of 1959. The actual launch attempt came in the following month, on August 21, at the NASA launch site, Wallops Station, Va. A nearly catastrophic failure occurred at a time late in the launch countdown as the vehicle battery-power supply was being charged. At this time, the escape-rocket sequence was unintentionally initiated and the spacecraft was separated from the launch vehicle and propelled into the air as in a pad-abort sequence. The escape sequence was accomplished correctly, though initiated by a fault. The tower was jettisoned properly, the drogue parachute was deployed as it should have been, but the main parachute deployment circuitry was not activated because of a lack of sufficient electrical power. The spacecraft was destroyed on impact with the water. The cause of the failure was determined by detailed analyses to be a "backdoor" circuit which permitted the launch-escape system to be activated when a given potential had been supplied to the battery by ground charging equipment. The launch vehicle, though fully loaded with six solid-propellant rocket motors, was left undamaged on the launcher.

*Big Joe 1.*—Spacecraft checkout for the launch of Big Joe 1 was accomplished at the Cape Canaveral launch site starting in June of 1959. The primary purpose of the flight was to investigate the performance of the ablation heat shield during reentry, as well as to investigate spacecraft reentry dynamics with an instrumented boilerplate spacecraft. Other items that were planned for investigation on this flight were afterbody heating for both the exit and reentry phases of flight, drogue and main parachute deployment, dynamics of the spacecraft system with an automatic control system in operation, flight loads, and water-landing loads. Recovery aids, such as SOFAR bombs, radio beacons, flashing light, and dye markers, had been incorporated. This spacecraft was not equipped with an escape system. The mission was accomplished on September 9, 1959. Because of the failure of the Atlas booster engines to separate, the planned trajectory was not followed exactly, but the conditions which were achieved provided a satisfactory fulfillment of the test objectives. The landing point of the spacecraft was about 1,300 nautical miles from the lift-off point, which was about 500

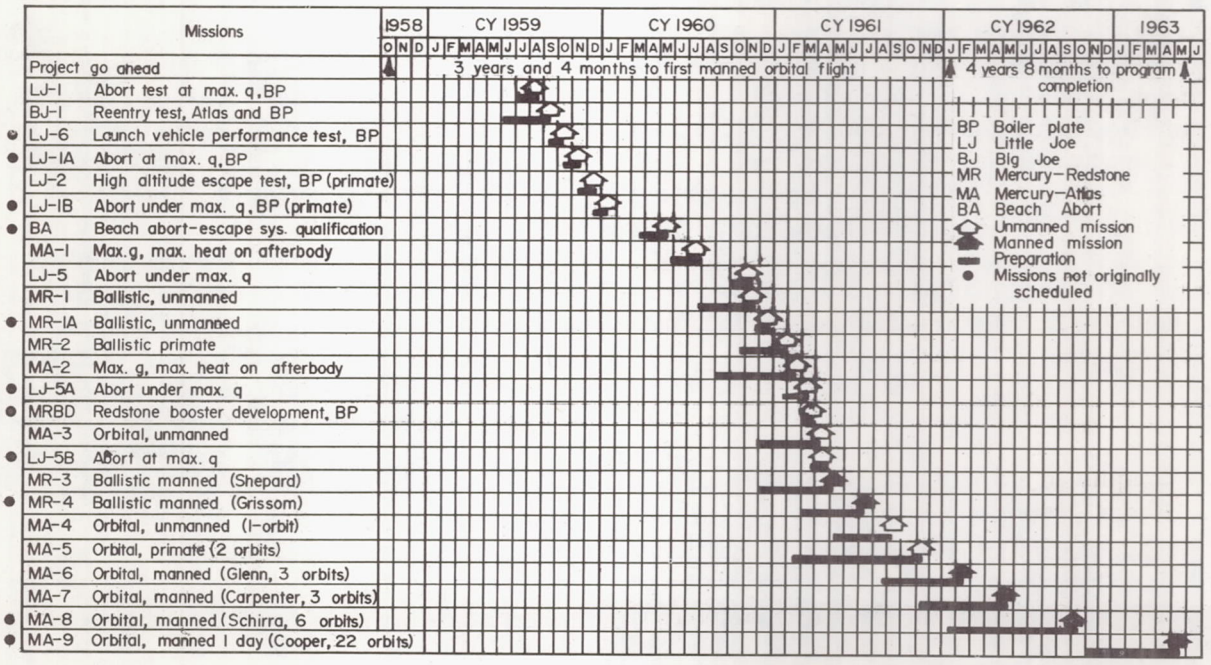



FIGURE 1–3.—Actual flight schedule.

nautical miles short of the intended landing point. Even so, the recovery team retrieved the spacecraft about 7 hours after landing.

Data from instrumentation and results of inspection of the spacecraft showed that the heat-protection method planned for the production spacecraft was satisfactory for a normal reentry from the planned orbit. On the basis of these results, the backup Big Joe mission was cancelled.

*Little Joe 6.*—The Little Joe 6 mission was successfully accomplished on October 4, 1959, from the Wallops Station launch site and demonstrated a qualification of the launch vehicle by successfully flying with staged propulsion on a trajectory which gave structural and aerodynamic loads in excess of those expected to be encountered on the other planned Little Joe missions. In addition, a method devised for correcting the launcher settings for wind effects, the performance of the booster command thrust termination system, and the launch operation were checked out satisfactorily. Two minor modifications were made to the Little Joe vehicle as a result of this flight to protect the second-stage rocket motor and the launch vehicle base from heat radiated from the thrusting motors.

*Little Joe 1A.*—Little Joe 1A was launched on November 4, 1959, from the Wallops Station launch site, as a repeat of the Little Joe 1 mission. The inflight abort was made, but the first-order test objective was not accomplished because of the slow ignition of the escape rocket motor. This slow ignition delayed spacecraft-launch-vehicle separation until the vehicle had passed through the desired test region. All second-order test objectives were met during the flight and the spacecraft was successfully recovered and returned to the launch site. All other Mercury hardware used in this test, principally the major parts of the escape and landing systems, performed satisfactorily.

*Little Joe 2.*—The Little Joe 2 mission, which was intended to validate the proper operation of the spacecraft for a high altitude abort, was accomplished on December 4, 1959, from the Wallops Station launch site. The abort sequence was initiated at an altitude of almost 100,000 feet and approximated a possible set of abort conditions that could be encountered during a Mercury-Atlas exit flight to orbit. In addition to the first-order objectives, the spacecraft reentry dynamics behavior without a control system was found to be satisfactory. The spacecraft dynamic stability on descent through the atmosphere was found to be as expected. Additional information was obtained on the operation of the Mercury parachute, the Mercury spacecraft flotation characteristics, and the operational requirements of spacecraft recovery by surface vessels. A monkey was a passenger on this mission; both the monkey and the spacecraft were recovered in satisfactory condition at the end of the mission.

*Little Joe 1B.*—The Little Joe 1B mission was successfully accomplished on January 21, 1960, from the Wallops Station launch site. This mission had been added to the flight schedule because of the failures of Little Joe 1 and Little Joe 1A to meet the test objectives. On this mission, all test objectives were successfully met, with the accomplishment of an abort at the conditions described for Little Joe 1A. This spacecraft also had a monkey as a passenger. Both the monkey and the spacecraft were recovered satisfactorily at the end of the mission.

*Beach Abort 1.*—Mission Beach Abort 1 (BA–1) was accomplished on May 9, 1960, from the Wallops Station launch site and marked the first time that a production spacecraft underwent a major qualification flight test. Production spacecraft 1 was a reasonably complete spacecraft and contained many systems that later spacecraft would be equipped with. It was launched on an abort sequence from a launcher on the ground. The escape-rocket motor provided the impulse as it would on an escape from a launch vehicle while still on the pad. The test was successful and the feasibility of an abort from a pad was adequately demonstrated. Though the mission was successful, certain modifications to spacecraft equipment were found to be desirable after the performance of these systems was analyzed. Although separation of the escape tower was accomplished, it was not considered satisfactory because of the small separation distance provided. This resulted in the redesign of the escape-system jettison rocket-motor nozzles. The single nozzle was replaced by a tri-nozzle assembly to prevent rocket-motor performance loss by impingement of the exhaust plumes on the escape-tower structure. This modification proved to

be satisfactory and was retained for the remainder of the Mercury program. Another anomaly was the poor performance of the spacecraft telemetry transmitters. Investigation showed that the cause of this poor performance was a reversal of the cabling of the transmitter systems; thus, for the first time in the program, inadvertent cross connection of connectors had been deleted.

*Mercury-Atlas 1.*—The Mercury-Atlas 1 (MA–1) vehicle was launched from the Cape Canaveral test site on July 29, 1960. The primary purpose of the MA–1 flight was to test the structural integrity of a production Mercury spacecraft and its heat-protection elements during reentry from an exit abort condition that would provide the maximum heating rate on the afterbody of the spacecraft. The spacecraft involved was production item 4 and was equipped with only those systems which were necessary for the mission. An escape system was not provided for this spacecraft. The mission failed about 60 seconds after lift-off. The spacecraft and launch vehicle impacted in the water east of the launch complex. Because of this failure, an intensive investigation into the probable causes was undertaken. As a result of this investigation modifications were made to the interface area between the launch vehicle and the spacecraft to increase the structural stiffness. This inflight failure and subsequent intensive investigation resulted in a considerable delay in the launch schedule and the next Mercury-Atlas launch was not accomplished until almost 7 months later.

*Little Joe 5.*—The Little Joe 5 vehicle was launched on November 8, 1960, from the Wallops Station launch site. The test was intended to qualify a production spacecraft. It was a complete specification spacecraft at that time with the following exceptions: the landing-bag system was not incorporated; the attitude stabilization and control system was not fully operational, but was installed and used water to simulate the control system fuel; and certain components of the communications system not essential to the mission were omitted. The mission failed during flight when the escape-rocket motor was ignited before the spacecraft was released from the launch vehicle. The spacecraft remained attached to the launch vehicle until impact and was destroyed. The exact cause of the failure could not be determined because of the condition of the spacecraft components when recovered from the ocean floor and because of the lack of detailed flight measurements. The results of the analyses attributed the failure to components of the sequential system, but the cause could not be isolated. The sequential systems of spacecraft 2 and 6 were modified to preclude the possibility of a single erroneous signal igniting the escape-rocket motor.

*Mercury–Redstone 1 and 1A.*—The Mercury-Redstone 1 (MR–1), which was to provide qualification of a nearly complete production spacecraft number 2, in flight with a Mercury-Redstone launch vehicle, was attempted on November 21, 1960, at the Cape Canaveral launch site. The mission was not successful. At lift-off, the launch-vehicle engine was shut down and the launch vehicle settled back on the launcher after vertical motion of only a few inches. The spacecraft also received the shutdown signal and its systems reacted accordingly. The escape-rocket system was jettisoned and the entire spacecraft landing system operated as it had been designed. Analyses of the cause of malfunction showed the problem to have been caused by failure of two ground umbilicals to separate from the launch vehicle in the proper sequence. In the wrong sequence, one umbilical provided an electrical path from launch-vehicle power through blockhouse ground and the launch-vehicle engine cut-off relay coil to launch-vehicle ground that initiated the cut-off signal. Except for loss of expendable items on the spacecraft, such as the escape system and the parachutes and the peroxide, the spacecraft was in flight condition. The launch vehicle was slightly damaged in the aft section by recontact with the launcher The spacecraft and launch vehicle were demated. The launch vehicle was replaced by another Mercury-Redstone launch vehicle, and the spacecraft was again prepared for its mission. Modifications included a long ground strap that was placed between the launch vehicle and the launcher to maintain electrical ground until umbilicals had been separated. The refurbished spacecraft and new Mercury-Redstone launch vehicle were launched successfully as mission MR–1A on December 19, 1960. At this time, all test objectives were met. All major spacecraft systems performed well

throughout the flight. The launch-vehicle performance was normal except for a higher than nominal cut-off velocity. The only effects of this anomaly were to increase the range, maximum altitude, and maximum acceleration during reentry. The spacecraft was picked up by a helicopter 15 minutes after landing and was delivered back to the launch site on the morning after the launch.

*Mercury–Redstone 2.*—The MR–2 mission was accomplished on January 31, 1961, from the Cape Canaveral test site with a chimpanzee as a passenger. Production spacecraft 5 was used. The mission was successful and the majority of the test objectives were met. Analyses of launch-vehicle data obtained during the flight revealed that launch-vehicle propellant depletion occurred before the velocity cut-off system was armed and before the thrust chamber abort switch was disarmed. This combination of events resulted in an abort signal being transmitted to the spacecraft from the launch vehicle. The spacecraft reacted correctly to the abort signal and an abort sequence was properly made. The greater than normal launch-vehicle velocity combined with the velocity increment obtained unexpectedly from the escape-rocket motor produced a flight path that resulted in a landing point about 110 nautical miles farther downrange than the planned landing point. This extra range, of course, was the prime factor in the 2 hours and 56 minutes that it took to locate and recover the spacecraft. The chimpanzee was recovered in good condition, even though the flight had been more severe than planned. By the time the spacecraft was recovered, it had nearly filled with water. Some small holes had been punctured in the lower pressure bulkhead at landing. Also, the heat-shield retaining system was fatigued by the action of the water and resulted in loss of the heat shield. Another anomaly that occurred during the flight was the opening of the spacecraft cabin inflow valve during ascent, which prevented the environmental control system from maintaining pressure at the design level. Because the pressure dropped below the design level, the emergency environmental system was exercised, and it performed satisfactorily. From the experiences of this flight, a number of modifications were made to the spacecraft systems to avoid recurrence of the malfunctioning items. These modifications included the following:

(1) An additional fiber glass bulkhead was installed between the heat shield and the large pressure bulkhead to protect the bulkhead during landing, and items in the large pressure bulkhead area that could be driven "dagger-like" through the larger pressure bulkhead during the landing were removed or reoriented.

(2) The heat-shield retention system was improved with the addition of a number of cables and cable-retention devices. The modified heat-shield retention system was proved to be capable of retaining the heat shield to the spacecraft in rough seas for periods of up to 10 hours.

(3) Tolerances of the inflow valve detent system were changed to assure positive retention during periods of vibration.

*Mercury–Atlas 2.*—The Mercury–Atlas 2 vehicle was launched from the Cape Canaveral test site on February 21, 1961, to accomplish the objectives of the MA–1 mission. The space vehicle for this flight consisted of the sixth production spacecraft and Atlas launch vehicle No. 67–D. Several structural changes made in the spacecraft launch-vehicle interface area as a result of the failure of the preceding Mercury–Atlas missions were as follows:

(1) The adapter was stiffened.

(2) The clearance between the spacecraft retropackage and the launch-vehicle lox tank dome was increased.

(3) An 8-inch-wide stainless-steel band was fitted circumferentially around the upper end of the launch-vehicle lox tank.

(4) The lox-valve support structure was changed so that the valve was not attached to the adapter.

(5) Special instrumentation was installed in the spacecraft launch-vehicle interface area to measure loads, vibrations, and pressures.

The major test objective of the MA–2 mission was to demonstrate the integrity of the spacecraft structure, ablation shield, and afterbody shingles for the most severe reentry from the standpoint of load factor and afterbody temperature. The flight closely matched the desired trajectory, and the desired temperature and loading measurements were obtained. The spacecraft landed in the planned landing area and was recovered and placed aboard a recovery ship approximately 55 minutes after it was

launched. A preliminary evaluation of measured data and a detailed inspection of the recovered spacecraft indicated that all test objectives were satisfied and that the spacecraft structure and heat-protection elements were in excellent condition.

*Little Joe 5A.*—The Little Joe 5A mission was accomplished on March 18, 1961, from the Wallops Station launch site. This was an added mission, as a result of the failure of the Little Joe 5. For the Little Joe 5A mission, production spacecraft 14 and the sixth Little Joe launch vehicle to be flown were used. The spacecraft was a basic Mercury configuration with only those systems installed that were required for the mission. As during the Little Joe 5 mission early ignition of the escape-rocket motor occurred. The mission was unsuccessful. However, unlike the Little Joe 5 mission, a backup spacecraft separation system was initiated by ground command and successfully separated the spacecraft from the launch vehicle and released the tower. Because of the severe flight conditions existing at the time of parachute arming, both main and reserve parachutes were deployed simultaneously. They filled and enabled the spacecraft to make a safe landing. All other active systems operated properly except that the cabin pressure-relief valve failed to maintain the spacecraft cabin pressure because of a piece of safety wire found lodged in the seat. The spacecraft was recovered and returned to the launch area in good condition. Analysis of data from the spacecraft proved that the early ignition of the escape rocket motor was caused by structural deformation in the spacecraft-adapter interface area. This early ignition permitted separation sensing switches to falsely sense movement and give the signal for the remainder of the sequence. The corrections applied were to reduce air loading in the area by better fairing of the clamp-ring cover, by increasing the stiffness of the switch mounting and reference structures, and rerouting the electrical signals from these switches through a permissive network.

*Mercury–Redstone–Booster Development.*—The Mercury–Redstone–Booster Development (MR–BD) mission was made on March 24, 1961, from the Cape Canaveral launch site, with a Mercury-Redstone launch vehicle and the refurbished and ballasted Little Joe 1A research-and-development spacecraft. This flight was made as the result of the analyses of the performance of the launch vehicles on the Mercury-Redstone 1A and Mercury-Redstone 2 flights, which showed that there were some launch-vehicle problems that required correction and requalification. Most of these problems had to do with the overspeed performance that was attained during those missions. The flight was successful and analyses of the launch-vehicle data indicated that the launch-vehicle corrections were entirely satisfactory. No recovery of the spacecraft was attempted since it was used only as a payload of the proper size, shape, and weight, and no provisions were made to separate it from the launch vehicle during the mission.

*Mercury–Atlas 3.*—The Mercury–Atlas 3 (MA–3) mission was accomplished on April 25, 1961, from the Cape Canaveral test site. The planned flight, which was intended to orbit an unmanned production spacecraft once around the earth, was terminated about 40 seconds after lift-off by range-safety action when the launch vehicle failed to roll and pitch over into the flight azimuth. The spacecraft was aborted successfully as the result of the command signal and was quickly recovered. The spacecraft came through the abort maneuver with only minor damages. The performance of all spacecraft systems was generally satisfactory throughout the short flight. The spacecraft used on this mission was the eighth production unit. The launch vehicle, Atlas 100–D, had increased skin thickness in the forward end of the lox tank and had the abort sensing and implementation system installed for closed-loop operation. Analysis of records indicated that there was an electrical fault in the launch vehicle autopilot. Subsequent action resulted in closer examination of electrical components and connections.

*Little Joe 5B.*—The Little Joe 5B vehicle was launched on April 28, 1961, from the Wallops Station launch site. The vehicle was composed of Mercury production spacecraft 14A and the seventh Little Joe launch vehicle to be flown. The spacecraft, which had previously been used for the Little Joe 5A mission, had been refurbished with only those systems installed that were required for the mission. There was no landing bag and certain other

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nonessential systems were missing. It was the first spacecraft to be flight-tested with modified spacecraft-adapter clamp-ring limit-switch mountings and fairings. Also, the sequential system was modified to prevent the limit switches on the spacecraft-launch-vehicle clamp ring or the spacecraft-escape-tower clamp ring from closing any circuits which would ignite the escape rocket until the band separation bolts were fired. These changes in and around the spacecraft-launch-vehicle interface and in the sequential system were made as the result of the problems encountered in missions Little Joe 5 and Little Joe 5A. Because of a severe change in flight path as the result of the delayed ignition of one of the two main launch-vehicle rocket motors, the test was made at substantially more severe flight conditions than planned. The abort was planned to be initiated at a dynamic pressure of 990 lb/sq ft; instead the dynamic pressure had attained a value of about 1,920 lb/sq ft when the abort was initiated. However, the spacecraft escape system worked as planned and this test successfully demonstrated the structural integrity of the Mercury spacecraft. The spacecraft landed in the ocean after about 5 minutes of flight and was recovered and returned to the launch site in less than 30 minutes after launch. Analyses of the flight data and inspection of the spacecraft after the mission showed the spacecraft to be in good condition. An anomaly that showed up was the failure of two of the small spacecraft umbilicals to eject. Evidence indicated that these umbilicals failed to eject because of interference with the clamp-ring fairing after its release. This condition was corrected by changing the manner in which the fairing was supported on subsequent spacecraft. All test objectives were considered to have been met.

*Mercury–Redstone 3.*—The Mercury-Redstone 3 (MR–3) mission, the first manned space flight by the United States, was successfully accomplished on May 5, 1961, from the Cape Canaveral launch site. Astronaut Alan B. Shepard was the pilot. The space vehicle was composed of production spacecraft 7 and a Mercury-Redstone launch vehicle, which was essentially identical to the one used for the MR–BD launch-vehicle qualification mission. Analyses of the results of the mission showed that Astronaut Shepard satisfactorily performed his assigned tasks during all phases of the flight. Likewise, launch vehicle and spacecraft systems performed as planned. The spacecraft achieved an altitude of about 101 nautical miles and was in weightless flight for slightly over 5 minutes. Postflight examination of Astronaut Shepard and inspection of the spacecraft showed both to be in excellent condition. A helicopter pickup was made of the spacecraft after the pilot had made his egress from the side hatch of the spacecraft and had been hoisted aboard the helicopter. The pilot and the spacecraft were landed aboard an aircraft carrier 11 minutes after spacecraft landing, and the spacecraft was brought back to the launching site the morning after the flight.

*Mercury–Redstone 4.*—The Mercury-Redstone 4 (MR–4) flight was successfully made on July 21, 1961, from the Cape Canaveral launch site. Astronaut Virgil I. Grissom was the pilot. The space vehicle was made up of the 11th production spacecraft and a Mercury-Redstone launch vehicle essentially identical to the one used for MR–3 mission. The spacecraft on this mission was somewhat different from spacecraft 7, in that, for the first time, a manned spacecraft had a large top window, a side hatch to be opened by an explosive charge, and a modified instrument panel. The spacecraft achieved a maximum altitude of about 103 nautical miles, with a period of weightlessness of about 5 minutes. The flight was successful. After landing, premature and unexplained actuation of the spacecraft explosive side hatch resulted in an emergency situation in which the spacecraft was lost but the pilot was rescued from the surface of the water. Analyses of the data from the flight and debriefing by the astronaut indicated that, in general, the spacecraft systems performed as planned, except for the action of the spacecraft hatch. An intensive investigation of the hatch actuation resulted in a change in operational procedures. No fault was found in the explosive device.

*Mercury–Atlas 4.*—The Mercury–Atlas 4 (MA–4) vehicle was launched on September 13, 1961, from the Cape Canaveral launch site; it was a repeat of the MA–3 test and became the first Mercury spacecraft to be successfully inserted into orbit, returned, and recovered. Further objectives of this flight were to evaluate the

Mercury network and recovery operations concerned with orbital flight. The space vehicle for this flight was made up of Mercury–Atlas launch vehicle 88–D, with the same modifications as the launch vehicle used on the MA–3 mission, and the spacecraft which was used on the MA–3 mission. The spacecraft had been refurbished and designated 8A for this mission. This was a very complete spacecraft which included a man-simulator onboard to provide a load on the environment control system during orbital flight. Other differences between this spacecraft and spacecraft flown on subsequent missions were:

(1) The landing bag was not installed

(2) The spacecraft had small viewing windows rather than the large overhead window used on later spacecraft

(3) The spacecraft entrance hatch did not have the explosive-opening feature

(4) The instrument panel had a slightly different arrangement.

The launch vehicle provided the desired orbital path with a perigee of 85.9 nautical miles and an apogee of 123.3 nautical miles. The planned retromaneuver over the coast of California resulted in a landing in the Atlantic Ocean approximately 160 nautical miles east of Bermuda in the primary landing area. The spacecraft was recovered in excellent condition 1 hour and 22 minutes after landing. The mission achieved the desired objectives, even though certain anomalies showed up in systems behavior during the mission. None of the anomalies had serious consequence. The anomalies and action taken are as follows:

(1) A spacecraft inverter failed during the powered phases of flight. The cause was determined to be a vibration-sensitive component and found to be preventable by more precise and exacting acceptance tests.

(2) Some anomalies in the spacecraft scanner signals were detected during the mission. Steps were taken to modify the system to make it less sensitive to the effects of cold cloud layers.

(3) A leak developed in the spacecraft oxygen-supply system during the exit phase of the flight. The leak was small, and sufficient oxygen was available for the mission. Postflight analyses determined that the leak was caused by failure in a pressure reducer. The fault was corrected for subsequent missions.

(4) Some thrusters in the spacecraft automatic attitude control system had either reduced output or no output during the latter part of the orbit. Postflight analyses indicated that possibly the trouble was contamination of the metering orifices in some thruster assemblies.

*Mercury–Atlas 5.*—The Mercury–Atlas 5 (MA–5) mission was successfully made on November 29, 1961, from the Cape Canaveral launch site. A chimpanzee was the passenger on this flight. The mission was planned for three orbital passes and was to be the last qualification flight of the Mercury spacecraft and launch vehicle prior to a manned mission. The orbit was about as planned with perigee at 86.5 nautical miles and apogee at 128.0 nautical miles. Further objectives of this flight were to evaluate the Mercury network and recovery operations. In general, the spacecraft, launch-vehicle, and network systems functioned well during the mission until midway through the second pass when abnormal performance of the spacecraft attitude control system was detected and verified. This malfunction precluded the probably successful completion of the third pass because of the high rate of control fuel consumption. Accordingly, a retrofire command was transmitted to the spacecraft which resulted in it landing in the selected area at the end of the second pass. Recovery was completed 1 hour and 15 minutes after landing. The chimpanzee performed his assigned tasks without experiencing any deleterious effects during the mission and was recovered in excellent condition.

The primary anomaly during the mission was the control-system trouble which gave rise to increased fuel consumption by the attitude control system and which precipitated the abort of the mission at the end of the second orbital pass. The trouble was found to be a stopped-up metering orifice in one of the low-roll thrusters. Corrective action applied to subsequent missions included closer examinations for contamination in this system.

The spacecraft used for this mission was production spacecraft 9; and since it was the last qualification vehicle prior to the first manned orbital flight, it was intentionally made as nearly like the spacecraft for the manned mission as possible. This spacecraft included the large viewing window over the astronaut's head posi-

tion, the landing bag, a positive lock on the emergency-oxygen rate handle, an explosive-release type hatch, new provisions for cooling the inverters, and rate gyros modified to insure satisfactory operation in the vacuum condition. The launch vehicle, Atlas 93–D, was much like those launch vehicles used on the previous two Mercury–Atlas missions; however, some additional modifications were included on this vehicle. These modifications included a new lightweight telemetry system and a redundant path for the sustainer engine cut-off signal.

*Mercury–Atlas 6.*—Mercury–Atlas 6 (MA–6), the first manned orbital space flight made from the United States, was successfully made on February 20, 1962, from the Cape Canaveral test site. Astronaut John H. Glenn, Jr., was the pilot. The flight was planned for three orbital passes to evaluate the performance of the manned spacecraft systems and to evaluate the effects of space flight on the astronaut and to obtain the astronaut's evaluation of the operational suitability of his spacecraft and supporting systems. All mission objectives for this flight were accomplished. The astronaut's performance during all phases of the mission was excellent, and no deleterious effects of weightlessness were noted. In general, the spacecraft, launch vehicle, and network system functioned well during the mission. The main anomaly in spacecraft operation was the loss of thrust of two of the 1-pound thrusters which required the astronaut to control the spacecraft for a large part of the mission manually. The orbit was approximately as planned, with perigee at 86.9 nautical miles and apogee at 140.9 nautical miles. During the second and third passes, a false indication from a sensor indicated that the spacecraft heat shield might be unlocked. This indication caused considerable concern and real-time analyses resulted in the recommendation that the expended retropackage be retained on the spacecraft during reentry at the end of the third pass to hold the heat shield in place in the event it was unlatched. The presence of the retropackage during reentry had no detrimental effect on the motions of the spacecraft. Network operation, including telemetry reception, radar tracking, communications, command control, and computing, were excellent and permitted effective flight control during the mission. The spacecraft for this mission was production unit number 13 which was essentially the same as spacecraft 9 used in the MA–5 mission except for those differences required to accommodate the pilot, such as the couch, a personal equipment container, filters for the window, and some minor instrumentation and equipment modifications. The launch vehicle was Atlas 109–D. It differed from the MA–5 launch vehicle in only one major respect. For this launch vehicle, the insulation and its retaining bulkhead between the lox and fuel tank dome was removed when it was discovered that fuel had leaked into this insulation prior to launch. The spacecraft landed in the planned recovery area, close to one of the recovery ships. The spacecraft, with the astronaut inside, was recovered approximately 17 minutes after landing. The astronaut was in excellent shape.

Action to prevent recurrence of the anomalies encountered during the MA–6 mission included relocation of metering orifices and a change in screen material in the attitude control system thruster assemblies. Improved specifications, tighter quality control, and more conservative switch rigging and wiring procedures were applied to the sensors that indicated heat-shield release.

*Mercury–Atlas 7.*—The Mercury–Atlas 7 (MA–7) vehicle was launched on May 24, 1962, from the Cape Canaveral launch site. Astronaut M. Scott Carpenter was the pilot for this mission. The mission was planned for three orbital passes and was a continuation of the program to acquire additional operational experience and information for manned orbital space flight. All objectives of the mission were achieved. The spacecraft used for this flight was production unit number 18 which was very similar to the spacecraft 13 used on the MA–6 flight. Some of the more significant features and modifications applied to this spacecraft include: the SOFAR bomb and radar chaff were deleted, the earth-path and oxygen partial pressure indicators were deleted, the instrument observer camera was removed, provisions for a number of experiments and evaluation were added, a more complete temperature survey system was added, the astronaut's suit circuit constant-bleed orifice was deleted, the landing-

bag limit (heat-shield release) switches were rewired to prevent erroneous telemetry signals should one switch malfunction.

The launch vehicle, the Atlas 107–D, was similar to the previous Atlas launch vehicle except for a few minor changes, the major one of which was that for this mission, the fuel tank insulation bulkhead was retained. Launch-vehicle performance was satisfactory. A perigee of 86.8 nautical miles and an apogee of 145 nautical miles were the orbital parameters. During most of the flight, the spacecraft-system operation was satisfactory until, late in the third pass, the pilot noted that the spacecraft true attitude and indicated attitude in pitch were in disagreement. Because this control system problem was detected just before retrofire, no corrective action was possible and the astronaut was forced to provide manual attitude control, using the window and horizon as the attitude reference, for the retrofire maneuver. Retrofire occurred about 3 seconds late, and the optimum spacecraft attitudes were not maintained during retrofire. As a result, the spacecraft landed several hundred miles downrange of the planned landing point. Because of this, recovery of the astronaut was not accomplished until about 3 hours after landing. The spacecraft was retrieved later by a destroyer after about 6 hours in the water. Exact cause of the control system malfunction was not determined because the scanner circuitry suspected of causing the anomaly was lost when the antenna section was jettisoned during the landing phase. Changes in checkout procedures used in launch preparations were incorporated to prevent recurrence of this type of problem.

*Mercury–Atlas 8.*—The Mercury–Atlas 8 (MA–8) vehicle was launched from the Cape Canaveral launch site on October 3, 1962; Astronaut Walter M. Schirra, Jr., was the pilot. The MA–8 mission was planned for six orbital passes in order to acquire additional operational experience and human and systems performance information for extended manned orbital space flight. The objectives of the mission were successfully accomplished. The orbital parameters were as follows: perigee, 86.9 nautical miles; and apogee, 152.8 nautical miles. The space vehicle for this mission consisted of production spacecraft 16 and Atlas launch vehicle 113–D. The spacecraft was basically the same as spacecraft 18 utilized on the previous mission; however, a number of changes were made in the configuration to increase reliability, to save weight, to provide for experiments, and to conduct systems evaluations. The launch vehicle also had some changes as compared with the previous Mercury–Atlas launch vehicle. These changes include the following: the fuel tank insulation bulkhead was removed at the factory to be similar to the launch vehicle for the MA–6 mission, the two booster engine thrust chambers had baffled ejectors installed for improved combustion characteristics, and no holddown delay was programed between engine start and beginning of release sequence.

The pilot performed numerous experiments, observations, and systems evaluations during his mission. For the first time, extended periods of drifting flight were accomplished. Pilot adherence to the flight plan was excellent. Basic spacecraft systems, launch-vehicle systems, and ground-network systems performed well with only a few minor anomalies. The landing was made in the Pacific Ocean within sight of the primary recovery ship, and the spacecraft and pilot were recovered in about 40 minutes.

*Mercury–Atlas 9.*—The Mercury–Atlas 9 (MA–9) mission utilizing production spacecraft 20 and Atlas launch vehicle 130–D, was successfully accomplished on May 15 and 16, 1963, with Astronaut L. Gordon Cooper as the pilot. It was launched from the Cape Canaveral test site for a planned 22 orbital-pass mission. Launch-vehicle performance was excellent and a near perfect orbit was attained. The orbital parameters were as follows: perigee, 87.2 nautical miles; apogee, 144.2 nautical miles. For the first 18 orbital passes, the spacecraft systems performed as expected, and the pilot was able to adhere to the flight plan and perform his activities as planned. Up to that time, anomalies were limited to small nuisance-type problems. Beginning with the 19th orbital pass, the spacecraft systems problems began with actuation of the 0.05g warning light. Investigation of the occurrence of this warning light indicated that the automatic control system had become latched into the mode required for the reentry phase. Later, the alternating-current power supply for the control system failed to operate. These failures were analyzed by the pilot and the ground crew in real time

and it was determined that the pilot would have to make a manual retrofire and reentry. He performed these meneuvers with close precision and landed a short distance from the prime recovery ship in the Pacific. The pilot and the spacecraft were recovered and hoisted aboard the carrier only 40 minutes after landing. More detailed results of this mission are contained in other papers in this document.

Lift-off photographs of the three types of Mercury space vehicles are shown in figure 1–4.

## PERFORMANCE

An examination of the history of the major flight tests, presented in figure 1–3, will show that the basic objectives of the Mercury Project were achieved 3⅓ years after official project approval, with the completion of Astronaut John Glenn's successful orbital flight on February 20, 1962. Subsequently, Astronaut Carpenter completed a similar mission. Then, Astronauts Schirra and Cooper completed orbital missions of increased duration to provide additional information about man's performance capabilities and functional characteristics in the space environment. In addition, increasing numbers of special experiments, observations, and evaluations performed during these missions by the pilots as their capabilities were utilized have provided our scientific and technical communities with much new information. It is emphasized that goals beyond those originally established were achieved in a period of 4⅔ years after the beginning of the project with complete pilot safety and without change to the basic concepts that were used to establish the feasibility of the Mercury Project.

In early 1959, immediately after project goahead, the first manned orbital flight was scheduled to occur as early as April 1960, or 22 months before the event actually took place (see fig. 1–5). This difference was caused by an accumulation of events which included delays in production spacecraft deliveries, difficulties experienced in the preparations for flight, and by the effects of the problem areas that were detected during the development and early qualification flight tests. The primary problem areas included those which were associated with the spacecraft–launch-vehicle struc-

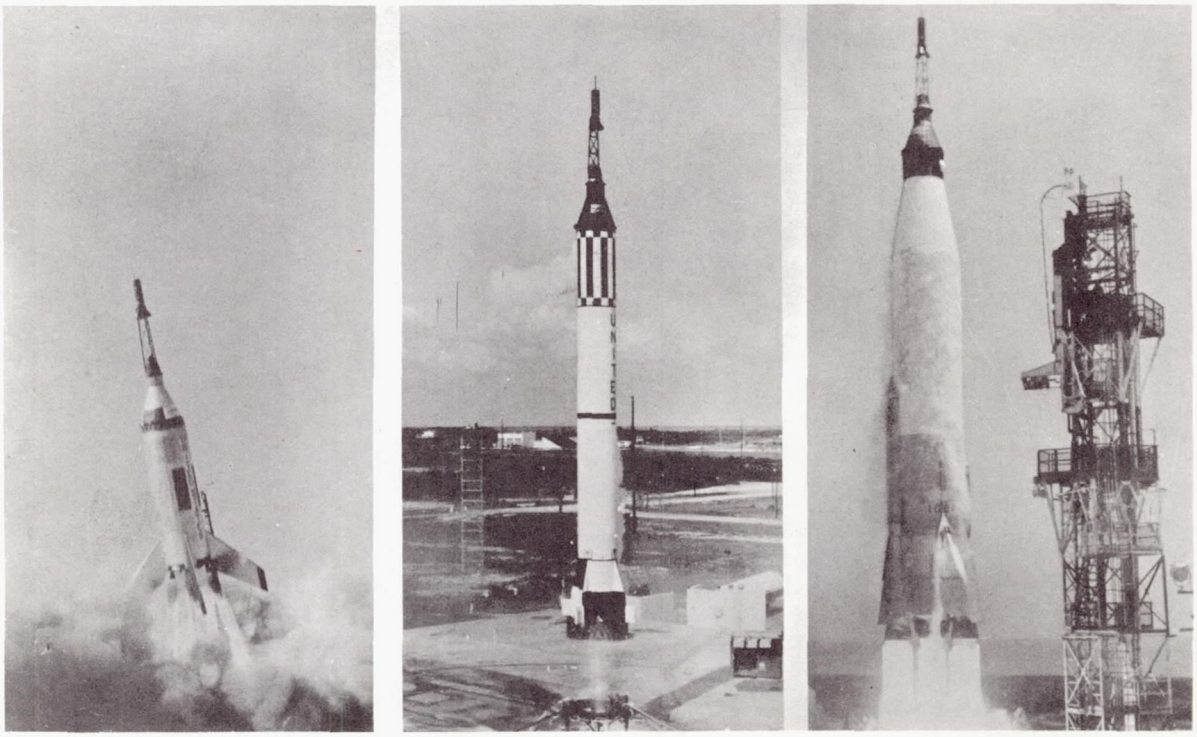



FIGURE 1–4.—Lift-off photograph of the three types of Mercury space vehicles.

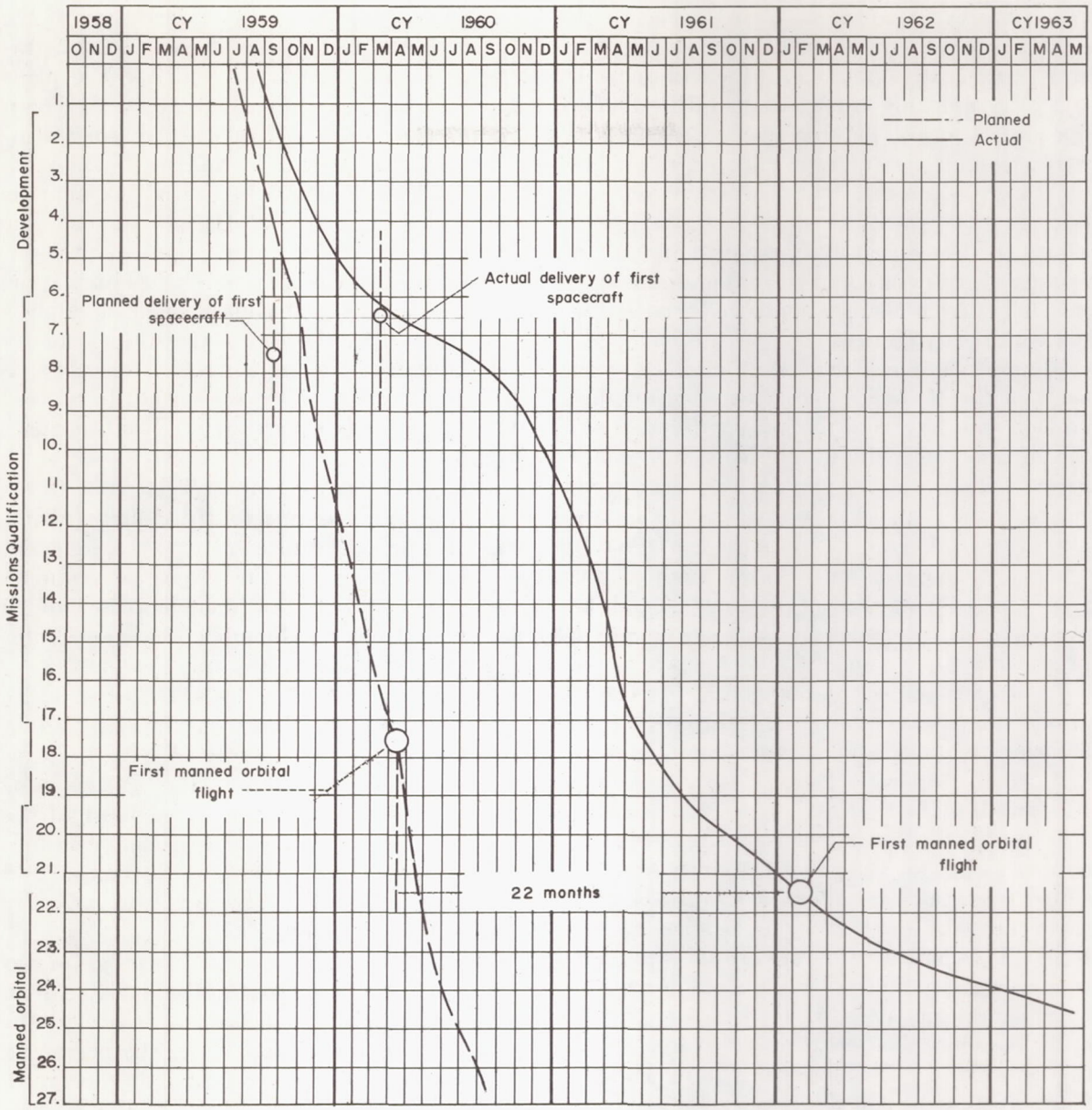



FIGURE 1–5.—Comparison of planned and actual flight schedules.

tural interface on the MA–1 mission, spacecraft sequential-system sensors on Little Joe missions 5 and 5A, launch-vehicle umbilical-release sequence on the MR–1 mission, launch-vehicle propulsion system on MR–2, and launch-vehicle control system on MA–3.

The applicability of these statements can be illustrated by reference line representations of the planned and actual schedules that are compared in figure 1–5. This comparison shows that the flight-test program was intiated about 1 month late. Missions through the development phase and those missions accomplished through most of the qualification phase were accomplished at about the planned rates. The major deviations occurred in 1960 when production spacecraft deliveries were later and when launch preparation took longer than planned. The planned schedule allowed for about a 4-week prelaunch preparation period at the launch site. Actual preparation time averaged about six times the estimated amount. Some of the additional required preparation time was compensated for by concurrent prepa-

ration of several spacecraft. Also, some significant problems were encountered during the early qualification missions which caused delays in the schedule by requiring additional missions to accomplish the objectives. These delays were accumulative and were not reduced during the life of the project. The delays that occurred later in the project resulted from deliberate efforts to insure that the preparation for the manned flights was complete and accurate and, still later, from changes made to increase the spacecraft capabilities.

Figure 1–3 shows that 25 flight tests were made in the 45-month period between the first mission and the end of the project, for an average of about one flight test in each 2-month period. This is a very rapid pace when the development and qualification nature of the program is considered. Even so, the average rate was low when compared with the rate that was maintained during the last part of 1960 and the early part of 1961 when five spacecraft were in preparation at once and the launchings occurred more frequently than once a month. It should also be noted that, during the period of high launch rate, preparations were accomplished at two widely separated sites, Cape Canaveral, Fla., and Wallops Station, Va.

While the flight missions were the significant outward signs of the project activity that resulted from the total effort, it was the behind-the-scenes activities that made the missions possible. The contents of figure 1–6 show the concurrent activity that existed in a number of the more significant areas of Project Mercury in order to reduce the time required to accomplish the objectives. The specific requirements in many areas were dependent upon the development being accomplished in the other areas. Thus, there was a continual iteration process carried on which resulted in a gradual refinement of requirements and completion of the work.

## Management

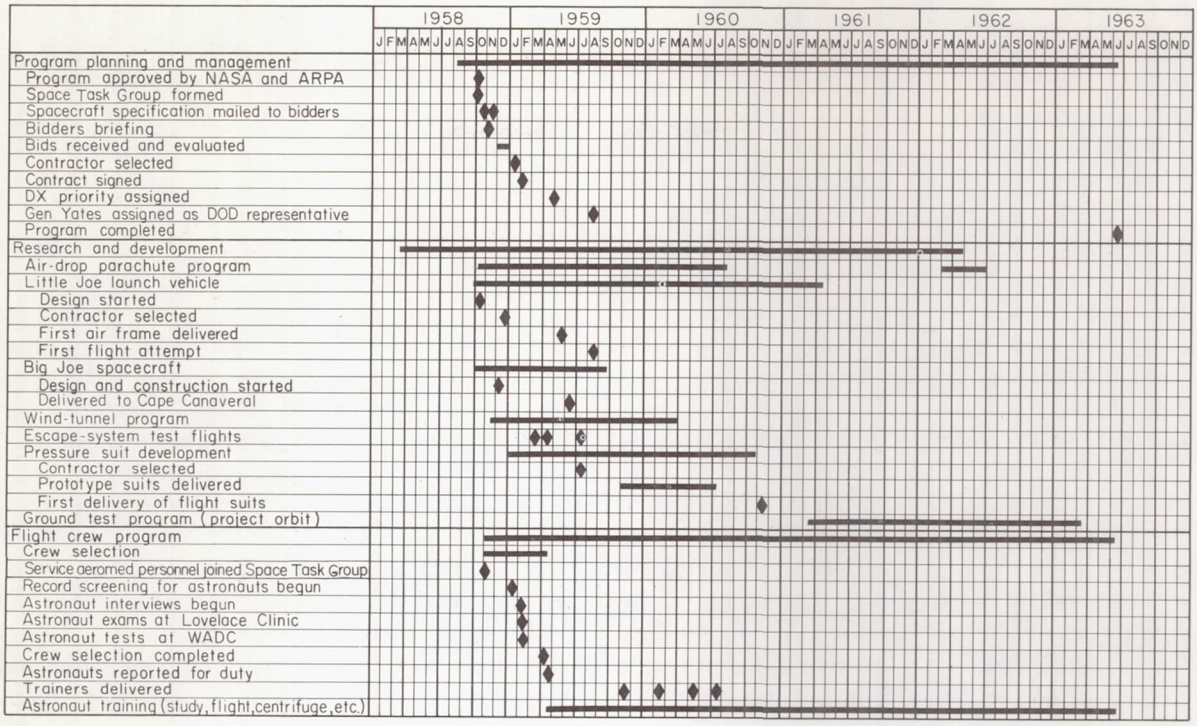
### Modes of Operation

Development of the management structure and operating mode to direct this complex and rapidly moving project began concurrently with the approval of the plans for a program of research and development leading to manned space flight which were presented to Dr. T. Keith Glennan, the first Administrator of the National Aeronautics and Space Administration (NASA) on October 7, 1958. The plans approved by Dr. Glennan on that date had been formulated by a joint National Advisory Committee for Aeronautics-Advanced Research Project Agency (NACA–ARPA) Committee, chaired by Dr. Robert R. Gilruth, at that time Assistant Director of Langley Research Center. The committee had been established during the summer of 1958 to outline a manned satellite program. With the approval of these plans by the Administrator of NASA, formerly the NACA, Dr. Gilruth was authorized to proceed with the accomplishment of the Manned Space Flight Project.

The Space Task Group (STG), later to become the Manned Spacecraft Center (MSC) was informally organized after this assignment to initiate action for the project accomplishment. The initial staff was comprised of 35 personnel from the Langley Research Center and 3 from the Lewis Research Center.

On November 5, 1958, the STG located at the Langley Research Center was formally established and reported directly to NASA Headquarters in Washington, D.C. At the same time, Dr. Gilruth was appointed head of the STG and project manager of the manned satellite program. By the end of November 1958 the manned satellite program was officially named Project Mercury.

The overall management of the program was the responsibility of NASA Headquarters, with project management the responsibility of the STG. It was recognized from the beginning that this had to be a joint effort of all concerned, and as such, the best knowledge and experience as related to all phases of the program and the cooperation of all personnel was required if success was to be achieved. It was also recognized that it was an extremely complex program that would probably involve more elements of government and industry than any development program before undertaken. Because of this complexity and involvement of so many elements, management was faced with an extremely challenging task of establishing an overall operating plan that would best fit the program and permit accomplishment of all objectives at the earliest possible date. To achieve



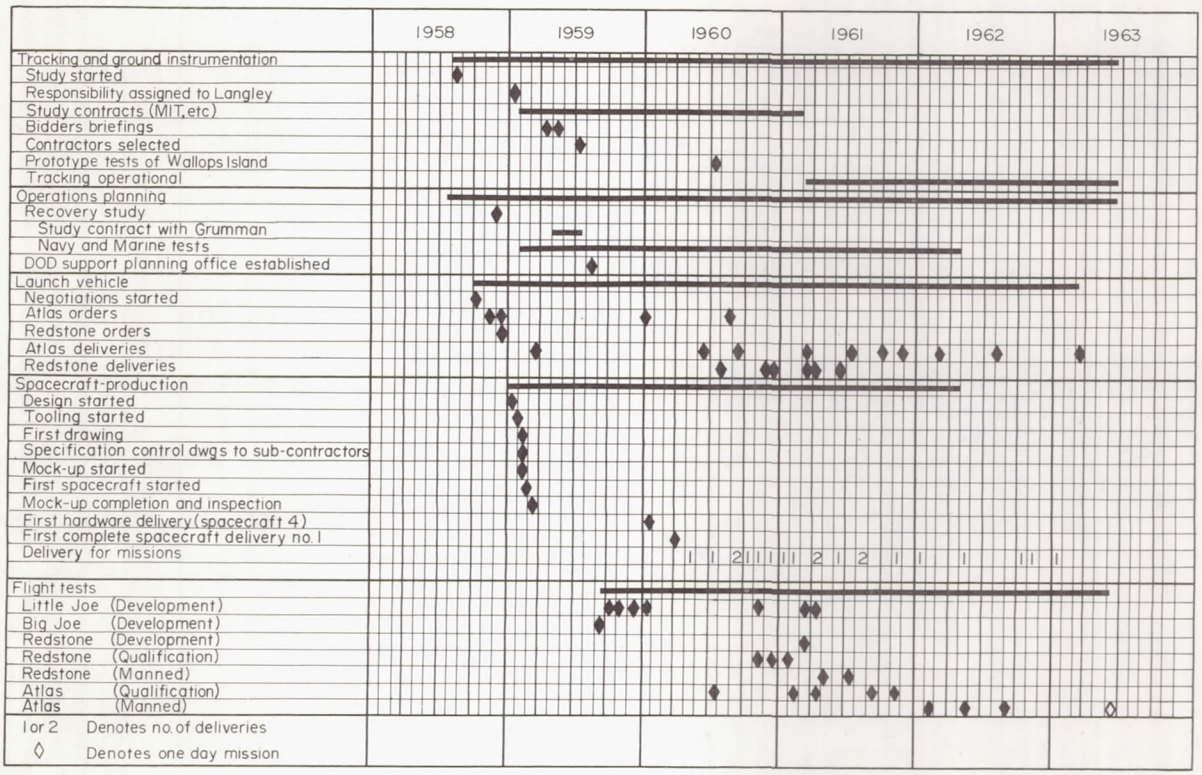




FIGURE 1–6.—Areas of primary activity during Project Mercury.

this task a general working arrangement was established as shown in figure 1–7. This figure illustrates in a very simplified format, the general plan used.

The arrangement was basically comprised of three working levels. The first level established the overall goals and objectives as well as the basic ground rules and the means for their accomplishment. The next level was responsible for establishing technical requirements and exercising detailed management. The detailed management was performed at this level and provided the approval and authorizing interface with all elements supporting the project. The bond of mutual purpose established here provided the direction and force necessary to carry the project forward. This same bond was evident in the groups or teams, in the third level of effort, set up to carry out the detailed implementation and, where necessary, further define the requirements. This level consisted of teams comprised of personnel from all necessary elements with responsibility for the assigned task and most knowledgeable in the area for which the group was responsible. These third level teams were established as required to investigate and define detailed technical requirements and insofar as possible to make the arrangements to implement their accomplishment. The team continued to function until all details of a particular technical requirement were worked out to the satisfaction of those concerned. As the tasks assigned to a particular team were completed, that team was phased out. New teams were established to meet new requirements which evolved and requirements of various phases as the project progressed.

An example of this working arrangement with a general explanation of how it worked is shown in figure 1–8. This example shows the arrangement used to procure and develop the Atlas launch vehicle for manned flight. To accomplish this, procurement agreements and overall policy were established between the U.S.

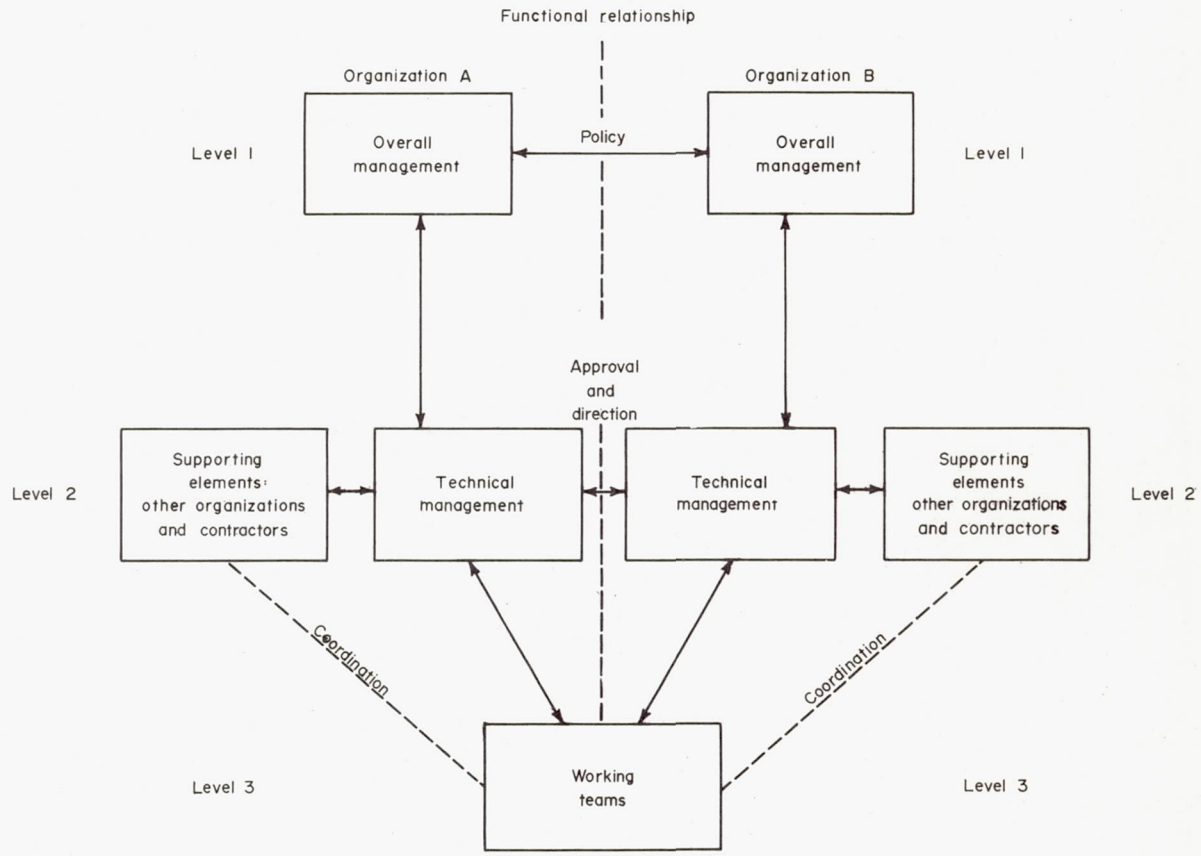



FIGURE 1–7.—Typical management arrangement.

Air Force Ballistic Missile Division of the Department of Defense and the NASA Headquarters. Working within the framework of these agreements the Atlas Weapons Systems Command of the U.S. Air Force and the NASA STG formulated the basic technical requirements necessary to adapt the Atlas for use in the program. Working teams consisting of specialists from the STG and the Atlas Weapons Systems Command were established to define the detail requirements and initiate the necessary action for their implementation. This implementation could be direct for cases in which the team had the authority or the recommendation for implementation could be forwarded to the necessary level of authority. In any case, the next higher level could alter the decisions of the lower level if developments required. This arrangement also provided a "closed-loop" management structure, thus assuring positive means of communication and proper technical directions. Frequently, specialists from the contractors and other supporting elements were included in the teams to assemble the best available talent to solve the problem. Quite often, tasks involving considerable effort were assigned directly to individual team members by the chairman of the group for implementation.

The same general arrangement was employed between NASA elements in accomplishing major tasks, such as establishing the Worldwide Tracking Network, as illustrated in figure 1–9. In addition to the many overall arrangements that had to be made in establishing the Worldwide Tracking Network, such as agreements with foreign governments, working through the State Department, regarding the location and operation of ground stations in their territory, the task of providing the hardware and facilities that made up the ground stations represented a major task that was primarily the responsibility of the STG and the Langley Research Center. This example covers the means by which the basic technical requirements and hardware needs of the ground stations were accomplished through the combined efforts of the STG and Langley. The Langley Research Center was responsible for the procurement and establishment of the network, with the basic flight monitoring and control requirements being the responsibility of the STG. The overall agreements regarding the implementation of this effort were established at the Director-Project Manager level with the basic technical requirements being defined at the level of the cognizant divisions. After the basic requirements were presented to the Langley Re-

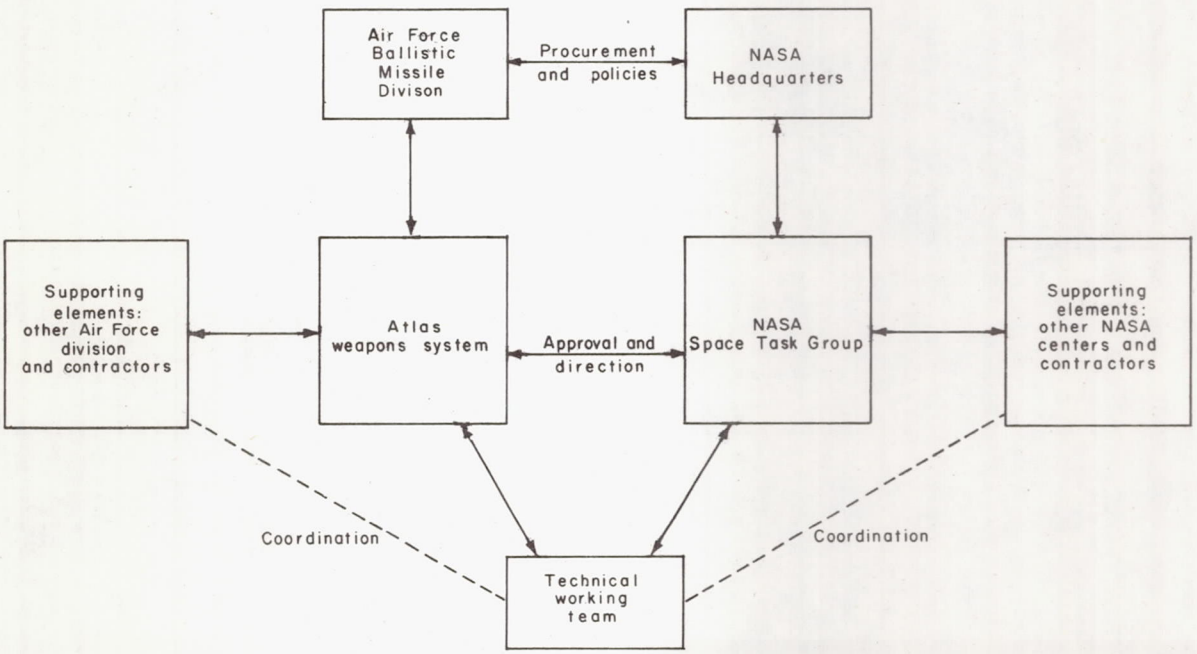



FIGURE 1–8.—Management arrangement used to procure, develop, and prepare the Atlas launch vehicle for manned flight.

search Center, teams were established to discuss and resolve the detail technical requirements of the network. For example, a team was assigned the task of establishing the communications and tracking requirements and resolving the type of equipment to be used on the spacecraft and the detail design characteristics of this equipment. They then had to determine if suitable receiving equipment for the ground stations was available or if it had to be developed. This involved coordinating overall requirements given to both the Langley Research Center's ground station contractors and the STG's spacecraft contractor to determine if the desired requirement could be achieved and if not, to determine an acceptable means of achieving the desired results. This points out only one detail area that this kind of group had to resolve; other areas such as location of the ground stations, frequencies of transmission, bandwidths, spacecraft antenna radiation patterns, and so on presented the same type of problems that had to be resolved. These efforts evolved into the Mercury Worldwide Tracking Network, the operation of which was the responsibility of the Goddard Space Flight Center (GSFC). Similar arrangements existed between the many elements necessary to develop the network and implement its operation.

To illustrate further this type working arrangement the identifications on figure 1–7 could be changed to represent those of the STG and the spacecraft contractor, McDonnell Aircraft Corporation (MAC). In this instance it was recognized by both parties that normal contractual procedures alone were insufficient to achieve the desired results within the scheduled time frame. Direct communication regarding technical requirements between the specialists of STG and MAC had to be the rule rather than the exception. Management agreements on the upper levels provided the framework whereby this could be accomplished and provided the management decisions for project direction. Frequently, the teams determined a course of action and proceeded without further delay, with verification documentation following through regular channels. The "closed-loop" built into the working arrangement provided the assurance that contractual and program requirements were met in all cases. Regular management reviews of hardware status and task achievement kept management abreast of the problem areas and afforded the opportunity for timely direction of effort to many specific problem areas. This mode of operation enhanced the rapidity with which a design change could be implemented or a course of action altered. This contributed to the timely conclusion of a project.

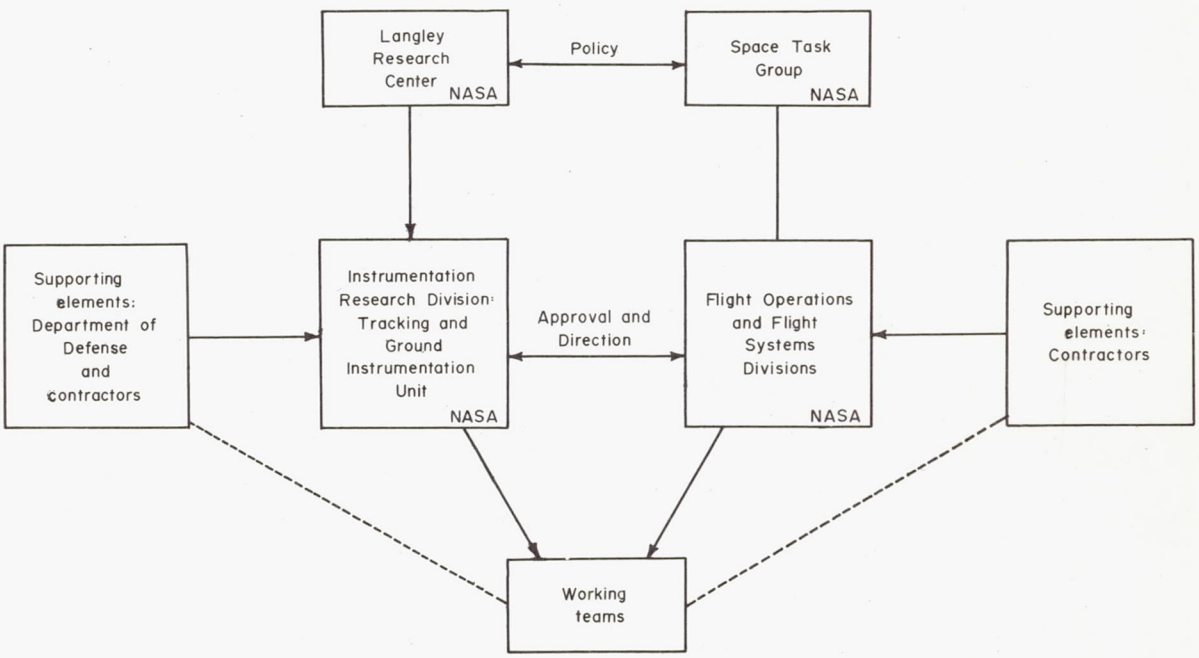



FIGURE 1–9.—Management arrangement used to establish the ground tracking organization.

The foregoing discussion is primarily concerned with the management techniques that existed with the external organizations, but the same type of procedure was commonly used within the organizational structure of the STG. As firm definition of the program emerged and final spacecraft design details were formalized, it became necessary to centralize the coordinating effort within the STG. To accomplish this, centralized review meetings were conducted on a regular basis to correlate all elements of the effort and ascertain that unified approaches and directions were maintained. These meetings were attended by cognizant personnel from within the STG and by personnel from other activities when required. The primary function of these meetings was to obtain the best inputs available for the technical management of the project and to control the engineering and design and thereby the configuration of the spacecraft. Information channeled into these meetings was dispersed directly to the responsible individuals within the STG, with assignments being made directly to the cognizant organization when action was required. Technical direction required as a result of action initiated at the coordination meetings, after thorough review as to need, cost, and effect on schedule, was issued to the applicable contractors. Meetings of this type provided fast response and accurate direction throughout the duration of the project. As the staff and project responsibilities increased, the support administrative functions performed by the Langley Research Center, such as Personnel, Procurement and Supply, and Budget and Finance Offices, were incorporated into the STG management organization.

The formation of the Mercury Field Operations Organization at Cape Canaveral marked the entry of Project Mercury into the operational phase of the program. In conjunction with this an Operations Director was appointed with complete responsibility and authority for flight preparation and mission operations. The Operations Director also served as the single point of contact for Department of Defense (DOD) activities supporting Project Mercury.

Although the general management modes of operation previously discussed were applied throughout the duration of the project, a different type functional organization was established for the specific purpose of conducting a space-flight mission. The organization covering the flight operations phase of the project was a line organization with elements from the government and contractor organizations involved in the operation reporting directly to the Operations Director. Figure 1–10 illustrates the manner in which these elements merged to form this functional line organization.

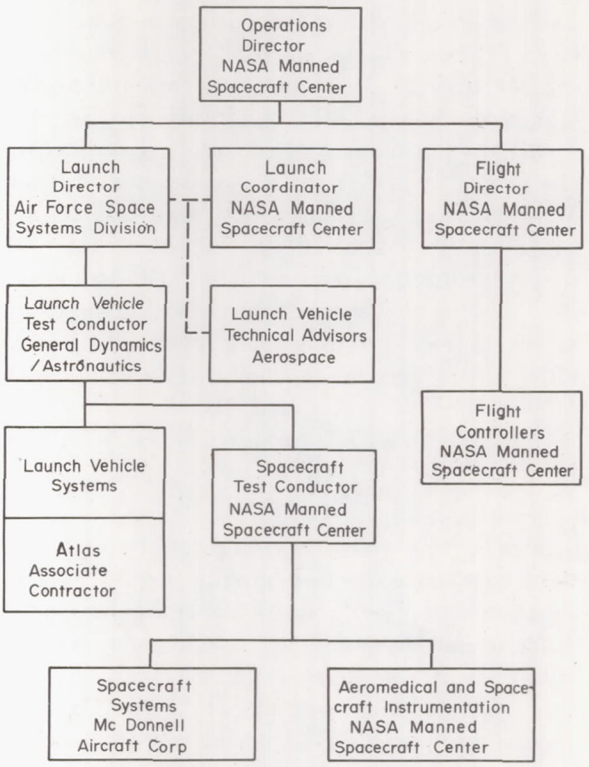



FIGURE 1–10.—Integrated functional organization for launch operations.

An organizational chart of this nature fails to show the unified effort, the cooperation, and the team work that was evident in every Mercury flight. All elements of government and industry supporting the project pulled together toward a common goal, with each individual striving to do his best. Without this spirit of cooperation and team work, the degree of success experienced in Project Mercury would not have been possible.

The success of Project Mercury demonstrated not only the reliability of the equipment but also the effectiveness of the management organization and the working arrangements with the various supporting elements throughout govern-

ment and industry. Efforts to assure that Project Mercury would meet its objectives evolved in the high level agreements that resulted in clear lines of authority and responsibility for technical direction.

With the increasing national effort in the field of space exploration, additional manned space projects were assigned to the STG. Because of the increased emphasis and scope of the manned spaceflight effort, the MSC was established in November 1961 from the nucleus provided by the STG. Soon after the MSC was established, the Mercury Project Office was created and assigned the responsibility and authority for detailed management and technical direction of the project, working with the support of other MSC units in areas in which they had cognizance or had specific specialties needed to achieve project objectives. The MSC organization existing at the end of the project is shown in figure 1–11. The Mercury Project Office provided the project management to the conclusion of the project and used the same general management method established early in the program.

### Tools

A reporting system was required by management to control the fast-moving project so that effective and timely decisions could be made. Various methods used by management to accomplish this included reports, schedules, cost control, and later, program evaluation and review technique (PERT) in addition to the technical reviews previously mentioned.

Many types of technical reports were prepared for management in order to keep it abreast of progress and problems. These reports were concise and factual status reports issued daily, weekly, monthly, and quarterly to highlight progress or lack of progress without conjecture. Obviously, close to the launch date, the daily reports became the most important. Another valuable report was the one prepared after the completion of each mission. These were prepared expeditiously to present analyses of the performance of all the systems involved in the mission, from the lowest elements through operational recovery techniques. The results of these analyses were used immediately after a mission to form the basis for corrective action that often influenced the hardware on the very next mission. These results were issued in formal report formats that contained detailed descriptions of the mission and equipment, performance analyses, result of investigations of anomalies, and much of the data. The reporting effort became greater as the complexity and duration of the missions increased, and larger reports and longer preparation times resulted. However, in most cases, the reports were printed for distribution within 30 days after the mission. The report of the MA–9 mission, for example, contained more than 1,000 pages of information.

Innumerable documents were generated covering all aspects of the program during the life of Project Mercury so that management as well as the individual elements could have overall knowledge of project details and progress. These documents were prepared by all elements participating in the program and included such general types as drawings, familiarization manuals, specifications, operational procedures, test procedures, qualification status, test results, mission results, reports on knowledge gained and status reports of all kinds. It is estimated that at least 30 formal documents, excluding drawings, engineering change orders, and so forth, were issued during the course of the project. A partial listing of the types of documentation used during the program is included in appendix A.

Overall schedule control was accomplished by the use of a Master Working Schedule which indicated major milestones, such as spacecraft deliveries and checkout periods, launch-vehicle deliveries and checkout times, launch-complex cleanup and conversion, and tracking network status. Detailed bar-chart schedules were maintained in areas of direct concern, such as individual spacecraft at the manufacturer's plant, launch preparation of the spacecraft and launch vehicle at the launch site, astronaut training, and the major test programs.

To control cost, management constantly monitored commitments, obligations, and expenditures through the normal accounting techniques. During the later phases of the program, the project office maintained cost control charts on which approved programed funds were shown, as well as obligations for a given time period. From these charts, management could tell at a glance the amount of remaining unobligated funds for any given area.

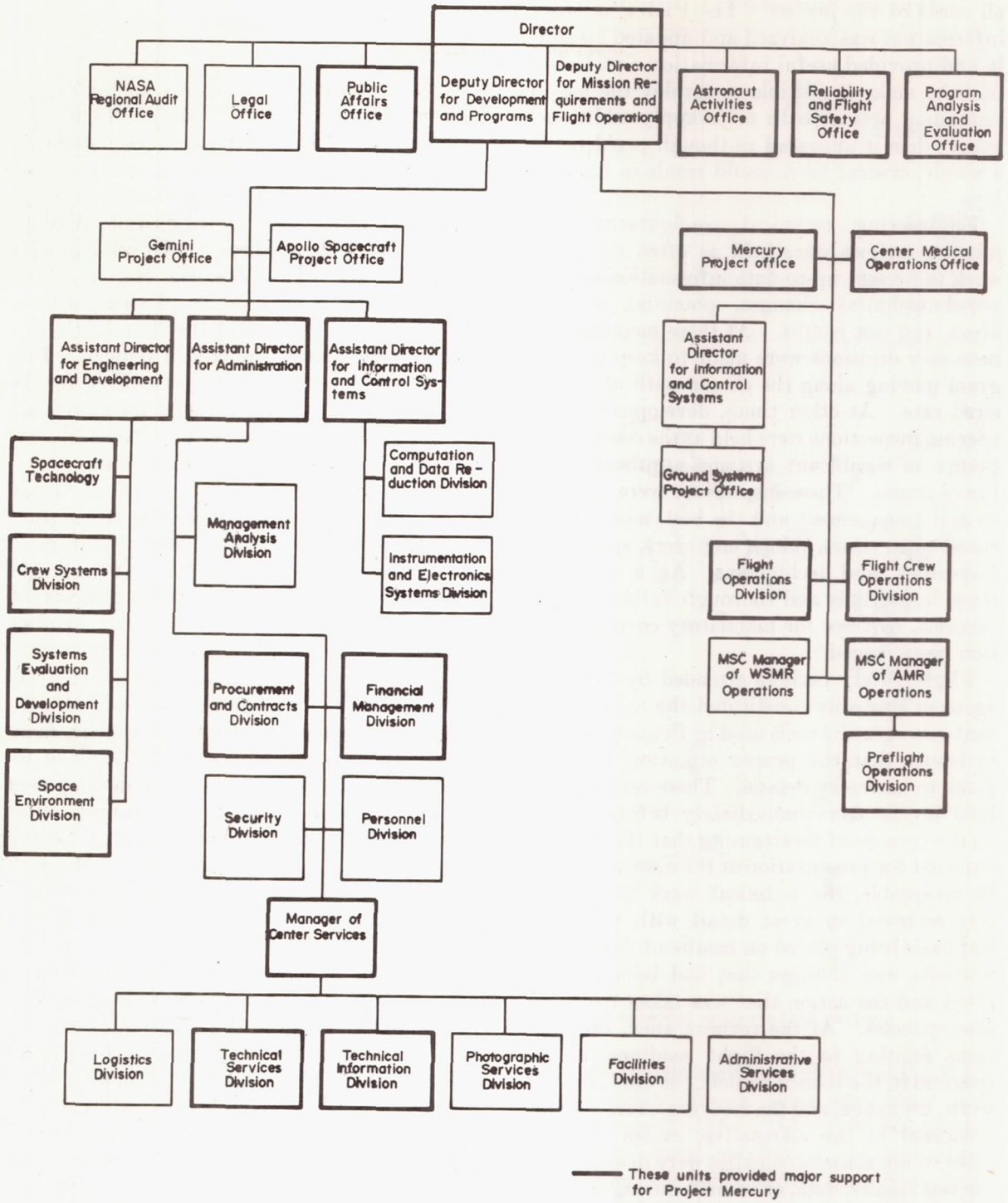



FIGURE 1–11.—Organization existing at end of Project Mercury.

In the last year and a half, the Manned Spacecraft Center applied the PERT system to cover all areas of the project. The PERT network information was analyzed and updated biweekly and provided useful information on a timely basis to make it possible to employ the use of redundant action paths or to apply additional effort when it appeared as though problems in a single, critical path would result in long delays.

Engineering, technical, configuration, and mission reviews were held as often as once a week to present up-to-date information on proposed technical changes, potential problem areas, and test results. At these meetings, the necessary decisions were made to keep the program moving along the chosen path at the desired rate. At other times, development engineering inspections were held at the contractors' plants as significant systems approached delivery status. These inspections were attended by top management and the best, most experienced supervisors, pilots, engineers, specialists, inspectors, and technicians. As a result of these inspections and thorough validating discussions, requests for mandatory corrective action were issued.

Flight safety reviews attended by top management probably constituted the most significant management tools used in Project Mercury to insure that the proper attention had been given to necessary details. These reviews were held in the days immediately before launch. In the process of ascertaining that the material required for presentation at the meetings would be acceptable, the technical work in progress was reviewed in great detail with particular emphasis being placed on results of tests, modifications, and changes that had been incorporated and the action that was taken to correct discrepancies. At the reviews, then, the questions relating to the flight readiness of the spacecraft, the launch vehicle, the crew, the network, the range, and the recovery effort could be answered in the affirmative, except in those cases where actual anomalies were discovered in the test results, data, or records during the presentation. Of course, these anomalies were then completely corrected or resolved, because no Mercury launchings were ever made in the face of known troubles or unresolved doubts of any magnitude that could affect mission success or mission safety.

### Resources

Many milestones occurred during the 57 months of the project as shown in figure 1–3. Mercury history reflects 25 major flight tests in a 45-month period. It should be noted that launch preparations and flights were accomplished from two widely separated sites: Cape Canaveral, Fla., and Wallops Station, Wallops Island, Va. Twenty-three launch vehicles were utilized—seven Little Joe, six Mercury–Redstone, and ten Mercury–Atlas. Two flight tests, the off-the-pad abort and the first Little Joe flight test, did not utilize launch vehicles. Fifteen production spacecraft were utilized for the flights, some of which were used for more than one flight mission or test unit. One spacecraft was used entirely for a ground test unit.

The broad range of effort which occurred, often concurrently, during the life of the project required the services of large numbers of people, as illustrated in table 1–I. At the height of this effort there were 11 major contractors, 75 major subcontractors, and 7,200 vendors working to produce the equipment needed for Project Mercury. Also included in this endeavor were the task forces from the DOD supplying ships, planes, medical assistance, manpower, and so on in support of flight and recovery operations. During the development and qualification phase of the project, effort was expended from Langley Research Center, Lewis Research Center, George C. Marshall Space Flight Center, Goddard Space Flight Center, Ames Research Center, Wallops Station, and DOD involving hundreds of people. Colleges and universities also investigated many different and significant facets of Project Mercury. At the height of the program, there were some 650 people working directly on Project Mercury in the MSC and over 700 more in other parts of the NASA. In all, it is estimated that there were more than 2,000,000 persons located throughout the United States who directly or indirectly provided support for the Mercury Program. The general locations of the major contractors, universities, NASA centers and other government agencies are illustrated in figure 1–12.

*Table 1–I.—Peak Manpower Support*

| Source | Approximate peak numbers | |
|---|---|---|
| NASA: | | 1, 360 |
| Direct | 650 | |
| Research and development | 710 | |
| Industry: | | 2, 000, 000 |
| Contractors (11) | 33, 000 | |
| Major subcontractors (75) | 150, 000 | |
| Vendors (7,200) | 1, 817, 000 | |
| Department of Defense | | 18, 000 |
| Educational groups | | 168 |
| Others | | 1, 000 |
| Total | | 2, 020, 528 |

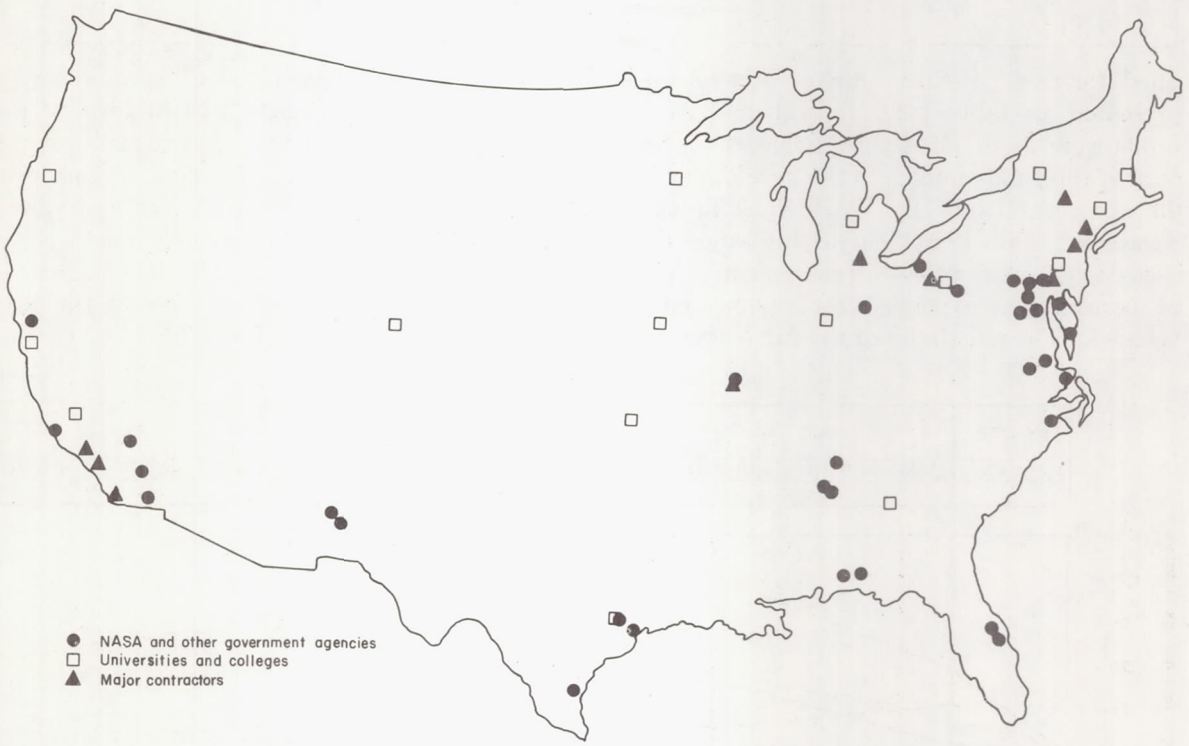



FIGURE 1–12.—Distribution of organizations in the United States that supported the project.

Lists of government agencies, prime contractors, and major subcontractors and vendors are presented in appendixes B, C, and D, respectively. A list of NASA personnel who contributed to the Mercury Project effort is presented in appendix E.

The total cost of the Mercury Program as published in the Congressional Committee Record in January 1960 was estimated to be $344,500,000. The basic objectives were fulfilled with the successful completion of the MA–6 flight and additional space experience was obtained from the MA–7, MA–8, and MA–9 missions. The latest accounting shows a total project cost of $384,131,000; however, final auditing has not been completed. These cost figures include the cost of the Mercury tracking network which will be used for manned space programs for years to come, and the cost of the operational and recovery support sup-

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*Table 1–II.—Cost Breakdown*

| Breakdown | Percent of total | | Cost in millions of dollars | |
|---|---|---|---|---|
| Spacecraft: | | 37. 6 | | 144. 6 |
| Design | 8. 6 | | 33. 2 | |
| Production | 5. 6 | | 21. 7 | |
| Test and flight preparation | 4. 2 | | 15. 9 | |
| Subcontract | 16. 2 | | 62. 2 | |
| Qualification | 3. 0 | | 11. 6 | |
| | 37. 6 | | 144. 6 | |
| Network | | 32. 4 | | 124. 6 |
| Launch vehicles | | 23. 7 | | 90. 9 |
| Operations | | 4. 3 | | 16. 4 |
| Supporting development | | 2. 0 | | 7. 6 |
| Total | | 100. 0 | | 384. 1 |

plied for each mission. A cost breakdown is presented in table 1–II, indicating how the funds were used. It is shown that the largest part of the funds went into the development of the spacecraft and the Worldwide Tracking Network. This is not surprising since these items required complete development. About 24 percent was expended for various launch vehicles. The remainder of the funds was spent for operational expenses and for supporting research and development. A breakdown of the spacecraft costs shows that approximately equal percentages were spent on design and on production. Almost one-half of the total spacecraft cost was spent on subcontracts by the spacecraft contractor.

The peak rate of expenditures in the program, as illustrated in figure 1–13, occurred dur-

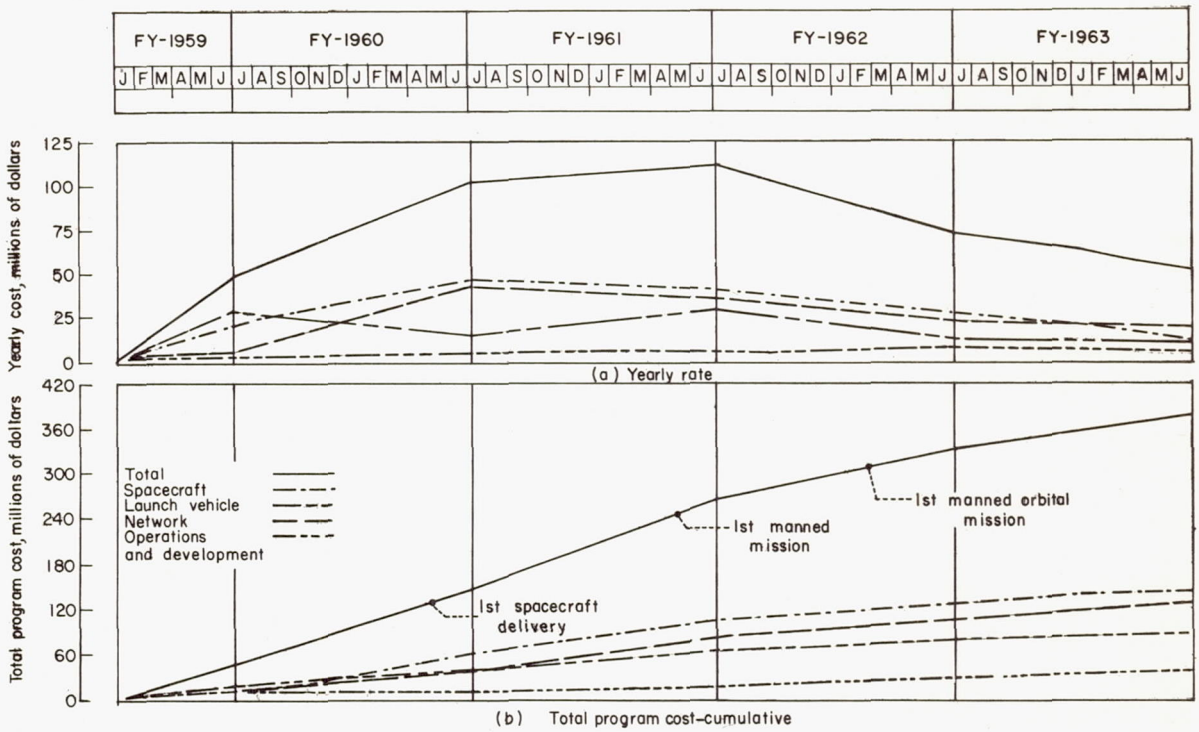



FIGURE 1–13.—Rate of expenditures and accumulated cost.

ing the fiscal year of 1961 and can be attributed to several factors. During this period, more than half of the total production spacecraft were delivered and more major flight missions were accomplished than in any other comparable time period. Launch activities were supported both at Wallops Station, Va., and at Cape Canaveral, Fla. Funds were being spent on the Worldwide Tracking Network for the coming orbital missions. The Redstone phase of flight program was nearing completion and the Atlas phase was approaching a peak. Also, much astronaut training was accomplished and the first manned ballistic flight was completed during this period.

## Technical Experience

The major results obtained and the significant philosophies and techniques developed during the course of the project are grouped for discussion in the following areas: physiological and psychological responses of man in the space environment, flight and ground crew preparational procedures, and techniques and philosophy for launch preparation.

### Responses of Man

The manned Mercury flights produced considerable information on human response and general physiological condition. Some of the most significant results may be summarized as follows:

(1) Results of repeated preflight and postflight physical examinations have detected no permanent changes related to the space-flight experience, although Astronauts Schirra and Cooper temporarily showed indications of orthostatic hypotension after their missions.

(2) There have been no alarming deviations from the normal, and the astronauts have proved to be exceedingly capable of making vital decisions affecting flight safety, taking prompt accurate action to correct systems deficiencies, accomplishing spacecraft control, and completing all expected pilot functions.

(3) The weightless state for the time periods of up to 34 hours has shown no cause for concern. Food and water have been consumed and the astronaut has slept. No abnormal body sensations and functions have been reported by the astronauts. The health of all of the astronauts has been good and remains so.

Not only has it been found that man can function normally in space, at least up to a maximum of 34 hours, but it has been found that he can be depended upon to operate the spacecraft and its systems whenever it is desired that he do so. On the MA–6 and MA–7 missions, the astronauts overcame severe automatic control system difficulties by manually controlling their spacecraft for retrofire and reentry. Also, on the MA–9 mission, the performance of the astronaut demonstrated that man is a valuable spacecraft system because of his judgment, his ability to interpret facts, and his ability to take corrective action in the event of malfunctions which would have otherwise resulted in a failure of the mission.

The astronauts also proved that they were qualified experimenters. As a result, the weight allocated in each succeeding manned orbital space flight increased from 11 pounds on MA–6 to 62 pounds on MA–9 for equipment not related to mission requirements. In each of these missions, the astronauts have demonstrated their ability to perform special experiments and to be a scientific observer of items of opportunity.

It can be concluded that the astronauts have proved to be qualified, necessary space systems, with flexible, wide-band-observation abilities, and have demonstrated that they could analyze situations, make decisions, and take action to back up spacecraft systems when provisions were made to give them the capability.

### Crew Preparation

Studies, simulators, and training equipment for preparing flight crews and simultaneous participation of flight and ground crews in simulated missions were important to the success of the mission. This training is discussed in detail in later papers of this document. Before the final round of training and simulation began, it was found necessary to formulate and freeze a well-defined, detailed flight plan. This must be done far enough in advance of the mission to give the pilot sufficient time to train to the particular plan with the ground network teams who will support him during the mission. It has also been found to be important to avoid filling every available moment of the flight with

a planned crew or ground-station activity. Time must be available to the flight crew to manage the spacecraft systems and to investigate anomalies or malfunctions in the system and to observe and measure the unexpected. Time must be provided to allow the pilot to consider thoughtfully his reactions to the space environment and its effects upon him. He must have time to eat and drink and to obtain sufficient rest. Training in simulator devices has proved to be a valuable tool for preparing a man for space flight. Well in advance of his flight, the pilot must have detailed training in the basic systems and procedures for the mission. In addition to preparing the pilot for normal and emergency flight duties, the training must also prepare him to conduct successfully the special experiments assigned to his mission. For certain of these tasks, the pilot becomes a laboratory experimenter and must be suitably trained. So far, many different training modes have been used to good advantage. These modes include lectures by specialists, discussions with the associated scientists, familiarization sessions with the specialized flight equipment before the flight, and parallel study in the field of the experiment. During the project, the special training given the astronauts produced trained experimenters for each mission.

#### Launch Preparation

In the process of hardware checkout during launch preparations, it has been found essential to have detailed written test and validation procedures, procedures that are validated and followed to the most minute detail during the preliminary systems checkout and, again, during later and final systems and integrated systems checkouts. It is necessary for the procedures to be so written that even small anomalies become readily apparent to those persons involved in the checkout. These persons must be so trained and indoctrinated that they are always watchful for anomalies which would be direct or indirect indications that the hardware may be approaching failure. Checkouts are not completed at the end of the detailed procedures, for it has been found that the data accumulated during a checkout procedure may reveal, upon detailed analyses, further symptoms that all is not well within a system. Finally, the Mercury personnel have developed and adhered to a philosophy that is believed to be a basic reason for Mercury's operational success. This philosophy is that Mercury launchings will not take place in the face of known troubles or in the face of unresolved doubts of any magnitude that could possibly affect mission success or flight safety. It is believed that adherence to this philosophy is of utmost importance to success of any manned space flight program.

### Areas for Improvement

A list of those general technical areas that appeared to be either the source of, or a major contributing factor to the problems that repeatedly cost the project time and money would include design requirements, qualification practices, definition of standards, tests and validation procedures, and configuration management. The conditions and effects described in these areas are not unique to this project, but represent those that generally exist in the aerospace field. Therefore, improvements in these areas would be beneficial in reducing the number of discrepancies that may potentially cause schedule delays and rising costs. Discussion of these areas will reveal that in most trouble areas careful and continuing attention to detail and quality assurance program were not as effective in the aerospace industry as necesary. It is believed that the need for improvements has become clear and that the changes for the space flight era are beginning to be made.

#### Design Requirements

Requirements and philosophies applied during the detail design phase have a profound and lasting effect on the overall performance of a project; therefore, some of the more significant shortcomings observed in the design phase are emphasized. Adequate design margins must be established and they must be adequate. An example where inadequate margins were detrimental is the weight-sensitive landing system. Experience with aircraft and spacecraft designs shows that weight continues to increase with time. In Mercury, this increase was significant; and although the rate tended to decrease with time, it was present throughout the duration of the project. The orbital weight of the spacecraft increased at an average rate about 5

pounds (0.2 percent) per week during 1959 and 1960; thereafter the increase averaged less than 2 pounds per week, even after a strong weight-control program had been initiated. The overall weight increase caused an extensive requalification of the landing system because the original design did not have sufficient growth margin. During the initial design phase careful consideration should be given to the use of redundancy. There are different forms of redundancy and the correct form must be chosen for the particular application to prevent degrading the overall reliability of the system. Because of the hazards of space flight and the lack of provisions for repairing or replacing equipment in flight, it was imperative in Mercury spacecraft that all critical functions have redundant modes. The redundancy was made less automatic, as man demonstrated the capability of applying the redundant function or providing the redundancy himself.

In the design of a spacecraft, consideration must be given to accessibility of components and assemblies. More than 3,000 equipment removals were made during the launch preparations on an early spacecraft; at least 1,000 removals were performed during preparations of the other production spacecraft. The majority of these removals occurred to permit access to a failed part. It is important that the design be such that a minimum number of other components have to be disturbed when it is necessary to replace or revalidate a component.

Since man first began making things, particularly with machines that could produce identical copies, he has found himself in the position where interchangeability is a combination of a blessing and a trap. Time and time again airplanes, automobiles, and other types of systems have had troubles and faults, because things that could be connected wrong have been connected wrong, regardless of printed instructions, colors, or common sense. Therefore, it is imperative that electrical connectors, mechanical components, and pneumatic and liquid connectors be so designed that they cannot physically be assembled in the wrong orientation or in the improper order. Experience shows clearly that this requirement cannot be overemphasized. Mismated or misconnected parts continued throughout the project to ruin components, give false indications of trouble, and result in improper functions that can cause test failure during the life of the project.

In the design of equipment for specific applications, consideration must be made for the shelf-life periods, including a margin for delays and extensions to the schedule. Occasionally in Mercury, these periods were not adequate and some equipment had to be replaced because the lifetime limit had been exceeded while still in storage.

Still another and often overlooked consideration is compatibility of materials. This may be related to the materials themselves, to the environment, or, in the case of manned vehicles, to the sensitivity of the man. In any event, care must be taken to see that only those materials properly approved for use in the vehicle are actually used. Time and money were expended in Mercury to rectify cases where improper materials were found in the systems because someone had failed to follow the approved materials list.

### Qualification Practices

Complete and appropriate qualification of components, assemblies, subsystems, and systems is essential for reliable performance of space equipment. In the design of the Mercury spacecraft, allowances were made for the unknown environment of the planned manned space-flight missions, by conservatism in design, by redundancy of equipment in systems, and, most important, by component qualification testing through ranges of environmental conditions that were believed to exceed the real conditions. The exact conditions that the components and equipment would be subjected to during Mercury space flights, of course, was unknown prior to the time of the flights. Therefore, care was taken in selecting the qualification conditions because underqualification could result in inflight failures, and drastic overqualification could cause unnecessary delays and high costs in the program. The selected qualification conditions proved to represent the actual environment conditions very well. Some modifications to the specifications were made as the project progressed to make allowances for specific environments, such as local heating in equipment areas and system-induced electrical "glitches." Complete coverage of conditions is important, but not sufficient if the qualification is not also appropriate. During the MA–9 mis-

sion, equipment faults occurred late in the mission which resulted in the failure of the automatic control system and required Astronaut Cooper to make his retromaneuver and reentry manually. These faults, which occurred in the electrical circuitry interfaces of the automatic control system, were caused by the accumulation of moisture. The components that suffered these faults had passed the Mercury humidity and moisture qualification tests; however, detail investigation revealed that one inappropriate step had occurred. The qualification procedures were set up so that the equipment was functionally validated before the test; however, during exposure to humid air and moisture, it was not functionally operated because it was not convenient to do so in the test facility. While it was being prepared for the posttest validation, it was given an opportunity to do some drying. The obvious fault was that the equipment was not required to operate during the entire course of the test. Of course, the weightless condition could not be simulated in these or any other ground tests and it is quite likely that this omission also played a role in this flight failure.

To be complete, qualification test requirements must be selected to cover all possible normal and contingent conditions and to allow for the integrated efforts that show up when a complete system is operated.

One way the qualification of a complete system has been accomplished in the project is through the use of full-scale, simulated environment tests. A spacecraft was completely outfitted with flight equipment and instrumented and tested under environmental conditions to reproduce as closely as possible the normal and abnormal, but possible, flight conditions. From these tests, it was possible to determine the effects of modifications and to demonstrate the performance of the integrated system. Almost 1,000 hours of this type of testing was accomplished, compared with less than 60 hours of actual space flight during the entire project.

#### Definition of Standards

It has become very apparent that certain standards that have been used for years in the aircraft industry must be revised and tightened to make them satisfactory for application to aerospace equipment. Among these are shop practices; for example, those practices used in preparing electrical wiring must be reevaluated to assure that each step is accomplished in a manner that meets high-quality standards. Insulation stripping, soldering, crimping or welding, and cleaning processes must be accomplished without degrading the materials and in such a way that the quality of the work can be verified. Requirements must be made more rigorous and must be thoroughly understood by the people performing the operations, by their supervisors, and by the inspectors to insure continuing high quality work.

Some space equipment is designed to close tolerances which make it very sensitive to contamination in any form; therefore, it is imperative that steps be taken to assure that proper and consistent cleanliness standards are set up throughout the manufacturing, assembly, validation, and checkout phases. A number of these cleanliness standards exist at the present time. However, what is considered clean by one standard may be dirty when compared with "clean" by a similar appearing standard. Steps are now being taken in the industry to formulate logical and consistent standards and it is necessary to implement and to enforce these standards as soon as possible to prevent recurrence of the continual difficulty caused in this project by contamination that ruined metering orifices, check valves, pressure regulators, relief valves, reducers, compressors, and other mechanical equipment, as well as electrical and electronic equipment.

#### Test and Validation Procedures

Checkout, test, and verification procedures must be compatible with one another and with procedures serving the same function on similar equipment at different test sites. Numerous cases of anomalies, or suspected malfunctions, and failed equipment have been traced to improper or incompatible test procedures and test mediums or equipment. Also, it was found that careful attention to test techniques is essential; otherwise equipment can be damaged because connections are made improperly or dirt can be introduced into the equipment by the test equipment. It has been found that test techniques must be tightened, verified, analyzed, and written in detail to lessen the chance for inadvertent steps to ruin the operation or give false assurance.

### Configuration Control

During the course of the project, considerable effort was expended by NASA and its contractors in maintaining an accurate definition of system configuration so that configuration management could be properly maintained. Much of this was manual effort that could not respond as rapidly to changes and interrogations as desired. At least 12 major documents, some of which were updated continually, some periodically, and some for each mission, were used to present the necessary information which was summarized for the desired definition. Component identification, which is essential to component traceability, also was often a tedious, time-consuming, and inaccurate process. To provide for adequate configuration control, it is important that vital information of systems, subsystems, and components be gathered at a central point. Then, provisions must be made to view this information from appropriate levels and directions so that accurate and responsive configuration management can be accomplished. Eventual incorporation of such a system on a national scale would provide a retrievable file to insure maximum use of technical experience and to lessen the chance of repeated errors.

## Bibliography


1. Staffs of NASA, Nat. Inst. Health, and Nat. Acad. Sci.: *Proceedings of a Conference on Results of the First U.S. Manned Suborbital Space Flight, June 6, 1961.*
2. Staff of NASA Manned Spacecraft Center: *Results of the Second U.S. Manned Suborbital Space Flight, July 21, 1961.* Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
3. Staff of NASA Manned Spacecraft Center: *Results of the First United Manned Orbital Space Flight, February 20, 1962.* Supt. Doc., U.S. Government Printing Office (Washington, D.C.)
4. Staff of NASA Manned Spacecraft Center: *Results of the Second United States Manned Orbital Space Flight, May 24, 1962.* NASA SP–6. Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
5. Staff of NASA Manned Spacecraft Center, Project Mercury: *Results of the Third United States manned Orbital Space Flight, October 3, 1962.* NASA SP–12, Supt. Doc., U.S. Government Printing Office (Washington, D.C.) Dec. 1962.
6. Bland, William M., Jr. and Berry, Charles A.: *Project Mercury Experiences.* Astronautics and Aerospace Engineering, Feb. 1963, pp. 29–34.
7. *Project Mercury: Man-In-Space Program of the National Aeronautics and Space Administration.* Report of the Committee on Aeronautical and Space Sciences, United States Senate. Eighty-Sixth Congress, First Session. Rep. No. 1014, December 1, 1959.
8. *Project Mercury, First Interim Report.* Staff Report of the Committee on Science and Astronautics, U.S. House of Representatives. Eighty-Sixth Congress, Second Session. 1960.
9. *Project Mercury, Second Interim Report.* Report of the Committee on Science and Astronautics, U.S. House of Representatives. Eighty-Seventh Congress, First Session. Union Calendar No. 241, House Rep. No. 671, June 29, 1961.
10. *Aeronautical and Astronautical Events of 1961.* Report of the National Aeronautics and Space Administration to the Committee on Science and Astronautics, U.S. House of Representatives. Eighty-Seventh Congress, Second Session, June 17, 1962.
11. *Astronautical and Aeronautical Events of 1962.* Report of the National Aeronautics and Space Administration to the Committee on Science and Astronautics, U.S. House of Representatives. Eighty-Eighth Congress, First Session. June 12, 1963.
12. Staff of NASA Manned Spacecraft Center: Project Mercury: A Chronology NASA SP–4001, Supt. Doc. U.S. Government Printing Office (Washington, D.C.).

# 2. PROJECT SUPPORT FROM THE NASA

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**Summary**

This paper outlines the contributions that were made to the Mercury Project by NASA organizations other than the Manned Spacecraft Center. These contributions began several years before the Mercury Project had official status through the basic research of the National Advisory Committee for Aeronautics which showed such a project to be feasible. The assistance provided by these organizations contributed directly to the timely development of the Mercury spacecraft and its systems, two of the three launch vehicles used in the Mercury program, and the Mercury Tracking Network.

**Introduction**

The efforts that were recently ended with the successful completion of the Mercury program did not begin with the initiation of the Mercury Project in late 1958 but, in reality, began several years before that date. The research conducted in the wind tunnels and other facilities of the National Advisory Committee for Aeronautics (NACA) in a decade preceding the Mercury Project established the concepts that eventually led to the Mercury Project. None of these original concepts needed to be changed during the Mercury program.

It is well known that the NACA provided its personnel and its facilities as a nucleus for the new agency when the NASA was established in October 1958. Almost immediately, a small group of scientists and engineers was organized at the Langley Research Center in Virginia to formulate plans for the Mercury Project. Many of this group were personnel of the Langley and Lewis Research Centers who had contributed to the original concepts of a man-in-space project in the preceding years. This organization became the Space Task Group (STG) and quickly began growing in size and capability. While the Space Task Group, and later the Manned Spacecraft Center (MSC), provided the direction and management of the Mercury Project, many thousands of scientists, engineers, technicians, and administrators throughout the NASA organization provided vital support for the Mercury Project. Without this support, Mercury could not have accomplished its goals within the time and costs that were realized.

It is appropriate to recognize that Langley Research Center is mentioned most frequently throughout this paper. The close association between Mercury and Langley is attributed to the fact that many of the original Space Task Group were personnel from the Langley Research Center and to the equally important fact that the STG and the MSC were physically located within the Langley Research Center for over 3½ years.

In addition to the formal technical support discussed in the following sections, administrative support was provided in the fields such as procurement, personnel, and security, by Langley in the initial phase of STG. The Launch Operations Center provided similar administrative support to the Mercury Field Office at Cape Canaveral.

**Spacecraft Development**

After a contract was awarded for the Mercury spacecraft, some 16 months passed before the contractor delivered the first production spacecraft. In order that full-scale tests could be conducted in the meanwhile, a large number of research and development spacecraft were constructed by NASA. These test articles were largely made of steel plate and, hence, have been called "boilerplates."

The boilerplates, which were made cheaply and quickly, resembled the Mercury spacecraft only in external configuration, in weight, and in center-of-gravity location. They were used primarily to obtain data on the performance of Mercury rocket motors and parachutes, and to obtain aerodynamic and thermal data needed for the design of the Mercury spacecraft.

In September, 1959, one of these boilerplates was flown through a ballistic flight by using the first Mercury-Atlas launch vehicle. This test, called Big Joe, was flown to gather thermodynamic data during reentry. This boilerplate was constructed in phases by both the Langley and the Lewis Research Centers. The Langley Research Center also provided the parachute landing system for the boilerplate and the Lewis Research Center designed and furnished the instrumentation and telemetry system. This successful flight test, in which the Langley and Lewis Centers played so large a part, provided valuable design data for the Mercury spacecraft.

The Langley Research Center also designed and constructed a series of boilerplates which were used in the Little Joe series of flights flown at Wallops Station, Va., in 1959 and 1960. The Little Joe tests were flown to prove the concepts of the launch escape system for inflight aborts at critical conditions and to evaluate the performance of this system.

Similar boilerplates were used in the Mercury program in drop tests for parachute-system qualification and as astronaut egress trainers until a Mercury spacecraft became available for this purpose. Much of the environmental qualification of equipment carried on all these boilerplates was conducted at Langley.

The many wind tunnels of the Langley, Lewis, and Ames Research Centers were used to perform tests early in the Mercury program to define the configuration of the Mercury spacecraft. Some 28 different wind-tunnel facilities conducted 103 separate investigations and accumulated over 5,300 hours of tunnel time by the end of 1960. These tests measured static and dynamic stability, pressure distributions, and heat-transfer data through subsonic, transonic, and supersonic speed regimes. Certain tests were made for vibration and flutter characteristics, and others to determine the correct size of the drogue parachute for stabilization. The Mercury escape and reentry configurations were tested alone and in combination with all of the launch vehicles in the Mercury program. Additional tests were made at Langley on alternate escape configurations, on the structural characteristic of the Mercury shingles, and on Mercury heat-shield materials. Langley also assisted in the data reduction and analysis of tests run outside of NASA, such as the buffet study made in a wind-tunnel at the Air Force Arnold Engineering Development Center.

Tests were conducted at Wallops Station, Va., early in the program to evaluate the escape system planned for the Mercury spacecraft. These tests used both boilerplate and production spacecraft with the production escape and landing systems. The first such tests were "off-the-pad" aborts. These tests were followed by inflight aborts from the Little Joe launch vehicle. Wallops supported these tests with radar tracking, optical tracking, photography, telemetry reception, data playback, and radio command functions. This support was in addition to providing normal launch and range-clearance support and shop and office facilities.

During the development of the propulsion systems for the Mercury spacecraft, special tests were conducted in a high-altitude wind tunnel at the Lewis Research Center to evaluate the performance of the escape rocket and retrorocket motors. The popgun effect of firing the posigrade rocket motors into the Mercury-Atlas adapter cavity between the spacecraft and the launch vehicle was measured. In addition, the effect of the escape rocket exhaust on the Mercury spacecraft window was evaluated.

Lewis also conducted developmental tests on the hydrogen peroxide reaction control system and on the manual proportional control system in the altitude chamber.

The Langley Research Center conducted a series of tests on the solenoid valves for the reaction control system thrusters. These tests were conducted in altitude chambers to determine the effect of vacuum on the valve. The results of the tests established that a vacuum did not affect the operation of a valve even when it was not operated for 24 hours. A method of evaluating the movement of the solenoid valve's seat by measuring the electric current flow (signature) was developed for these tests. This method of measuring the valve's signature was

later used for selecting valves that were acceptable for flight.

The development of the spacecraft landing system required an extensive series of tests which began at Langley Research Center in 1958. In the early development of the main parachute, drops were made at West Point and Wallops Island, Va., and at Pope Air Force Base, N.C. Langley supported these tests with personnel, aircraft, test vehicles, instrumentation, and tracking equipment. Later tests were made at the NASA Flight Research Center at Edwards Air Force Base, Calif., to develop the Mercury drogue parachute. For these tests, the Flight Research Center provided personnel, test vehicles, and all other facilities needed to accomplish the program. The development of the landing-impact skirt required the assistance of NASA facilities at Langley Research Center and Wallops Station.

In the development of the Mercury heat protection system, the Langley Research Center made numerous structural tests at elevated temperatures on samples of the ablation heat shield, the René 41 conical shingles, and the beryllium recovery-section shingles.

When a formal program was established by Manned Spacecraft Center to conduct special inflight experiments on Mercury flights which were not directly related to the mission objectives, other NASA organizations proposed and furnished many of the experiments that were performed. On all the manned orbital flights, the Goddard Space Flight Center and the NASA Headquarters Office of Space Sciences sponsored experiments related to astronomy and earth and space science in general. These organizations also provided assistance in the evaluation of all proposed experiments. Goddard provided special filters and other optional equipment used in making some of these space-science observations.

The flashing-beacon experiment flown on the MA–9 flight was designed, constructed, and qualified by the Langley Research Center. Langley also provided the balloon-drag experiments flown on MA–7 and MA–9. The Lewis Research Center proposed and furnished the zero-gravity experiment carried on the MA–7 spacecraft. On the MA–8 flight, a number of ablation materials were bonded to the recovery-section shingles to evaluate them for heat-protection on future spacecraft. Langley not only furnished two of these materials, but conducted many tests on samples of the coated shingles to assure a good bond and no degradation of the safety aspects of the MA–8 mission.

### Launch-Vehicle Development

The NASA centers were involved in the procurement and operation of two of the three launch vehicles used in the Mercury program—the Little Joe and the Redstone. The Little Joe was conceived early in 1958 by the same group at Langley that formulated the man-in-space program. This launch vehicle performed much of the qualification of the Mercury spacecraft at approximately one-sixth the cost of an Atlas. Shortly after the official start of Project Mercury, the Space Task Group requested Langley to accept the responsibility for the procurement of six flight vehicles and one test article. Accepting this responsibility, Langley performed the basic design of the vehicle, wrote the specification, evaluated contractors' proposals, and awarded and monitored the contract for detail design, construction, and testing. After delivery of the Little Joe vehicles, Langley provided personnel for the assembly, checkout, and launch of these vehicles at Wallops Station, Va. A command destruct system was also designed and provided by Langley for the first four Little Joe vehicles. In addition, Langley designed and constructed the spacecraft-launch-vehicle adapters for all Little Joe flights.

The Marshall Space Flight Center was instrumental in implementing the Mercury-Redstone program. Marshall's task was the provision of a launch vehicle for manned flight that had previously been used only for unmanned payloads of considerably lighter weight. Technical groups were formed to conduct studies and perform reliability and structural tests. As a result of these studies, a number of modifications were made in the Redstone launch vehicle to make it acceptable for manned flight. Major

modifications, made largely at Marshall, were made in some subsystems, and an Abort Sensing and Implementation System (ASIS) was designed for and integrated into the launch vehicle. Other work done at Marshall included compatibility testing of the spacecraft-launch-vehicle combination and static firing of each launch vehicle prior to delivery to Cape Canaveral. The resulting launch-vehicle reliability was a milestone in the Mercury program that contributed to the reduced requirement for only five Redstone flights instead of the eight originally programed.

Prelaunch checkout and launch operations for the Mercury-Redstone missions were conducted by the NASA Launch Operations Center at Cape Canaveral which was formerly the Launch Operations Division of the Marshall Space Flight Center. The Launch Operations Center now provides much support to the Manned Spacecraft Center at Cape Canaveral in many technical and administrative areas and in the provision of facilities.

### Mercury Network Development

Of considerable importance in the successful accomplishment of the Mercury missions was, of course, the worldwide Mercury Tracking and Communications Network. The responsibility for the development of this network was given to the Langley Research Center. A group formed at Langley in early 1959 wrote the specifications for the network and awarded a contract for its design and construction in July 1959. After the contract award, this Langley group continuously monitored and contributed to the design and development of the network facilities. The nerve center of the Mercury network is the automatic, high-speed computing equipment located at and operated by the Goddard Space Flight Center. Langley's responsibility for the network ended with the acceptance of the facilities by the government. Thereafter, the maintenance and operation of the Mercury network became the total responsibility of the Goddard Space Flight Center.

# I

# SPACE-VEHICLE DEVELOPMENT

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# 3. SPACECRAFT SYSTEMS DEVELOPMENT AND PERFORMANCE

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**Summary**

Project Mercury began in 1958 with some basic systems research and a number of feasibility studies to determine if a spacecraft could be built which would sustain man in orbital space and return him safely to earth. Although it was recognized that some system development would be required, many of the spacecraft systems could be synthesized from existing hardware. A top priority was placed on the spacecraft production from the contract award in 1959, and 3 years later Astronaut John H. Glenn, Jr., completed three orbital passes about the earth. In this time span, design, development, and qualification of the spacecraft and its systems were accomplished nearly concurrently. The ground and flight-test programs, which included hundreds of wind-tunnel tests and parachute drops from aircraft, provided an opportunity to develop flight systems and acquire operational experience as the program progressed. Though a continuing attention to engineering detail by technical specialists and management personnel throughout the project, the spacecraft and its systems were qualified for suborbital flight in approximately 2 years from the spacecraft contract award date. Many lessons have been learned which were not only applied to Mercury systems development, but which have been applied in more advanced space projects. Interesting conclusions regarding system performance can be derived by reviewing all of the flight results. The spacecraft control system was a source of considerable trouble during the project. However, when inflight failures of this type occurred, it was the backup capability of the pilot which made possible the successful completion of the mission. In fact, the pilot's ability to control accurately the spacecraft attitude was instrumental in three of the four manned orbital flights in completing the mission successfully when a malfunction was present in the automatic system. One of these control-system malfunctions, an electrical anomaly during Astronaut Cooper's mission and the only one of major significance in the spacecraft throughout the entire 34-hour flight, was successfully circumvented by the pilot's manual control during the critical retrofire and reentry maneuvers.

## Introduction

The initial goal of Project Mercury was to place a man into orbit successfully and return him safely to earth, and this objective was fulfilled in February 1962 by the flight of Astronaut John H. Glenn, Jr. This objective was confirmed 3 months later by the flight of Astronaut M. Scott Carpenter. The final two missions in Mercury constituted a continuation of a program to acquire new knowledge and operational experience in manned orbital space flight. The ninth Mercury-Atlas mission (MA–9) was planned for up to 22 orbital passes and was the concluding flight in the United States' first manned space program. The primary objectives of the MA–9 mission were to evaluate the effects on the astronaut of approximately 1 day in orbital flight, to verify that man can function as a primary operating system of the spacecraft; and to evaluate the combined performance of the astronaut and the spacecraft, which was specifically modified for the 1-day mission.

The MA–9 spacecraft, *Faith 7*, used by Astronaut Cooper in successfully performing the fourth United States manned orbital mission was basically similar to those used for previous orbital flights. The major exceptions were system modifications prompted by the extended nature of the mission, and these changes will be

discussed in later paragraphs. It is important to note, however, that since the original design of the Mercury spacecraft all major system concepts have remained essentially unaltered. Although some design and early development were conducted prior to the official award of the prime contract, the Mercury spacecraft was developed, qualified, and met its original objective of manned orbital flight 3 years after the spacecraft contract award in 1959. In this brief span of time, many lessons have been learned and much experience has been gained in the design, development, and operation of manned orbital flight systems. In this paper, the intent is to describe briefly the original design philosophy, discuss the system development and qualification experiences, and present a summary of the experiences relating to systems performance.

## Design Philosophy

In the initial design of the Mercury spacecraft, two guidelines were firmly established: (1) to use existing technology and off-the-shelf equipment wherever practical and (2) to follow the simplest and most reliable approach to system design. These guidelines were administered to provide for the most expedient realization of program objectives. The original Mercury concept also included a number of mandatory design requirements which were imposed on the spacecraft contractor:

(1) The spacecraft must be fitted with a reliable launch-escape system which would rapidly separate the spacecraft with its crew from the launch vehicle in case of an imminent disaster.

(2) The mode of reentry into the earth's atmosphere would be by drag braking only.

(3) The spacecraft must carry a retrorocket system capable of providing the necessary impulse to bring the vehicle out of orbit.

(4) The spacecraft design should place prime emphasis on the water-landing approach.

(5) The pilot must be given the capability of manually controlling spacecraft attitude.

In many design areas, there existed no previous experience in reliable system operation which could be applied to the Mercury concept, and new development programs had to be initiated. In addition, there was no information pertaining to man's capability to operate under space environmental conditions, particularly weightlessness; therefore, all of the spacecraft systems which relate to crew recovery from orbit had to be designed for automatic operation and many had to include redundancy. It has since been learned that man is not only a contributory element but a necessary part of the spacecraft. It is important to note that because of the pilot's demonstrated ability to function as a primary operating system of the spacecraft, some of the redundant elements were not required and were deleted.

The spacecraft systems (fig. 3–1) include the heat protection, mechanical and pyrotechnic spacecraft control, communications, instrumentation, life support, and electrical and sequential systems. The mechanical and pyrotechnic system group comprises the separation devices, the rocket motors, the landing system, and the internal spacecraft structure. These systems have been described in previous literature (refs. 1 to 10); therefore, detailed descriptions are not included in this paper.

The design requirements stated earlier involved certain implications for these systems. The launch-escape system was found to be most practical if it incorporated a solid rocket motor to propel the spacecraft rapidly away from the launch vehicle during an abort in the atmosphere. This type of system needed to provide a high level of thrust for a brief time period should be easily handled in the field and should require a minimum of servicing. The tower arrangement could be readily assembled to the spacecraft and jettisoned during powered flight once it no longer was required for abort.

An important design feature of the Mercury spacecraft was the favorable manner in which the astronaut was exposed to flight accelerations. For all major g-loads, which occur during powered flight, launch-escape motor thrusting, posigrade motor thrusting, retrograde motor thrusting, reentry, parachute deployment and touchdown, the pilot experienced acceleration in the most favorable manner, one that forces him into the couch (fig. 3–2).

The mode of reentry was specified to be drag braking only because of simplicity. This concept implied that the configuration should be a blunt body with high drag properties having a slender afterbody, primary because of heating considerations. Thus the bell shaped Mercury

configuration was evolved, and the heat-protection system was devised to accommodate this shape. Originally, a beryllium thermal shield employing the heat-sink principle was specified. The specification was later changed to provide a more efficient ablation-type heat shield, which was used on all Mercury–Atlas orbital missions. Because the heat flux was expected to be considerably less on the afterbody than at the heat shield, a combination of insulation and thin shingles constructed of an alloy to withstand high temperature was calculated to be sufficient in maintaining the temperature of the pressure vessel at a safe level. The exterior finish of the spacecraft body was intentionally made a dull black because of its high emissivity and, therefore, favorable thermal radiation properties.

Again, because of their reliability and ease of handling and servicing, solid propellants were chosen for the retrorocket system. For even greater reliability, however, a system of three solid rocket motors, any two of which would effect a safe reentry, was chosen. These three rocket motors, together with three additional rockets to effect spacecraft-launch-vehicle separation, were assembled in a jettisonable package to permit a clean reentry configuration.

For the period during and after touchdown, the spacecraft had to meet two basic requirements. These requirements were: (a) the structure had not only to retain its integrity such that it would be habitable after landing and (b) the touchdown decelerations had to be reduced to an acceptable level. Touchdown deceleration was primarily limited by the human tolerance to acceleration; and, because of the blunt shape of the spacecraft, touchdown decelerations of as high as 50g could have resulted even for a water landing. Therefore, a landing-shock attenuation system was designed which consisted of a fiberglass fabric bag with holes in it and was attached between the spacecraft structure and the ablation shield. Prior to landing, the ablation shield would be deployed and the shield weight would extend the bag, which would fill with air and provide a cushion against the landing shock. The landing bag arrangement adequately attenuated the landing deceleration loads to approximately 15g.

In addition to the automatic and rate control modes of the attitude control system, two manual control modes, one electrical and the other mechanical, were provided the astronaut. This control-mode arrangement had the feature that,

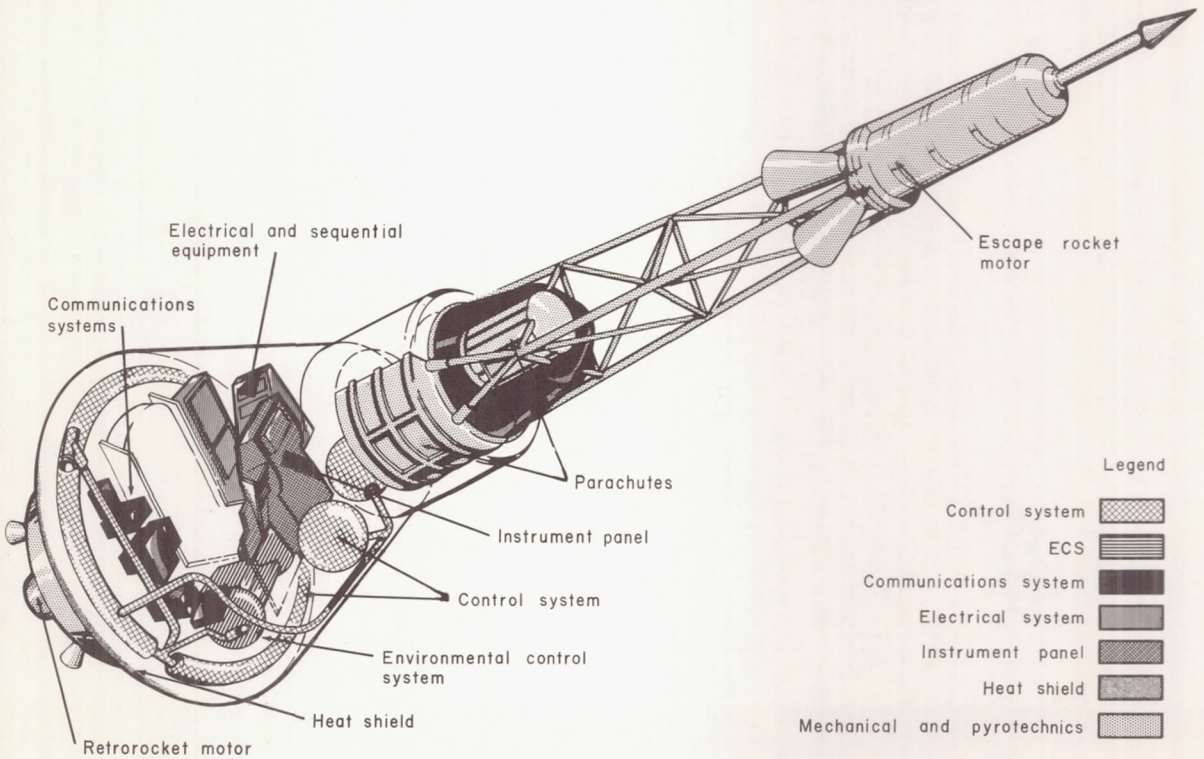



FIGURE 3–1.—Spacecraft interior arrangement.

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in the event of a spacecraft power failure, the direct-linkage mechanical mode would still be available for control. The two manual control modes were each supplied control-system fuel from separate tanks for additional reliability. Although the thrust units were designed to provide an impulse sufficient for the majority of spacecraft maneuvers, these redundant manual control modes could be used simultaneously, if desired, in critical situations, such as retrofire and reentry, where rapid response to undesirable attitude rates might become necessary.

A monopropellant reaction control system using hydrogen peroxide as the fuel was chosen for the spacecraft control system to provide the simplest system design and installation. Furthermore, similar systems had already been developed for use on other space vehicles. A flexible bladder under pressure provided a positive means of fuel expulsion.

Many challenging design problems were encountered in the remaining spacecraft systems because of the new operating environment. As a result of the need to provide flight-control support on the ground, the requirement for multiple redundancy and high reliability in the communications system was evident. Although part of the instrumentation system was not required for flight safety and mission success, certain parameters, such as those which indicate the psysiological well-being of the crew and the proper operation of critical spacecraft systems, were necessary for effective flight control and monitoring. The remainder of the instrumentation data was acquired to complement the flight-control parameters for use in postflight

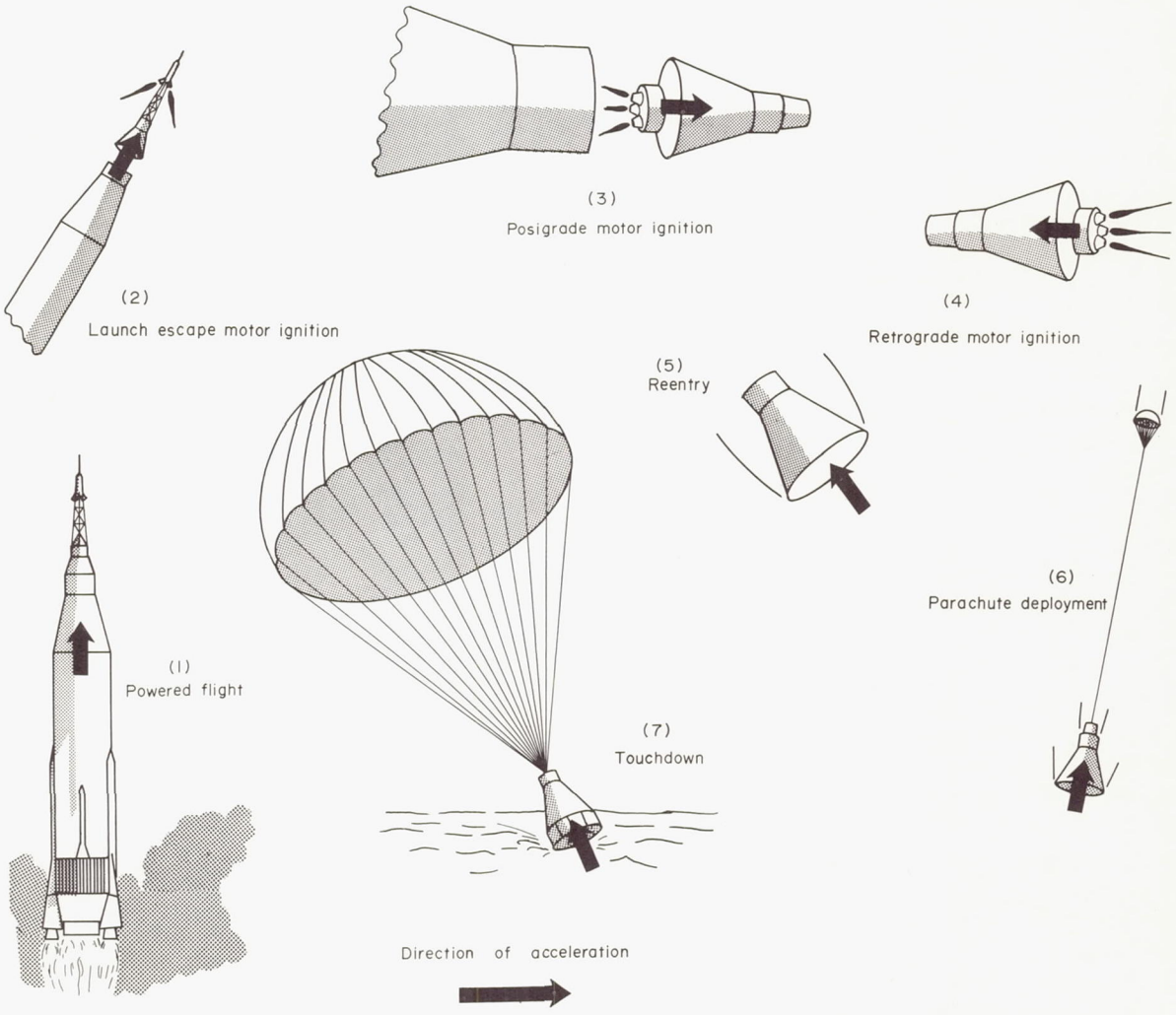



FIGURE 3–2.—Acceleration loading for various flight phases.

analyses of system performance. New design areas were opened up in the fields of gas partial pressure measurement and of bioinstrumentation, such as long term attachment of human sensor leads. The life-support-system design considerations involved a development task, since it was concerned with the sustenance of the astronaut and his protection from the hard vacuum of space, as well as from the widely varying temperature conditions associated with an orbital-flight profile. This system also was required to provide for the management of the cooling and drinking water in the spacecraft, the food to be consumed by the pilot, and his normal liquid wastes, again in the weightless environment. Although pressure suits and cooling equipment had been used in high-performance aircraft, only part of this experience could be directly applied to the design of the Mercury environmental control system because of weightless flight and more demanding performance requirements. In the electrical and sequential design area, the application of previous design work and use of off-the-shelf components was made. But the very nature of the mission and the requirement for reliability, automation, and system redundancy imposed a degree of complexity somewhat greater than any previous manned flight system. This increased electronic complexity, in turn, made it more difficult to insure interface compatability, eliminate stray voltages (back-door circuits), and minimize system sensitivity to current transients.

As an example of the consequences of stray voltages, the Little Joe–1 mission, the first launch attempt using a full-scale Mercury spacecraft, is cited. This test, conducted at Wallops Island, Va., was in the final moments of countdown when, during a spacecraft battery charging operation, a stray voltage initiated the launch escape sequence. The spacecraft was separated by the escape motor from the launch vehicle, and the drogue parachute was properly deployed. Because the battery had been only partially charged, sufficient current was not available to deploy the main parachute, and the spacecraft was destroyed upon landing. This back-door circuit was subsequently located and eliminated.

Because of work conducted immediately prior to and in the early period following contract award, the system-design phase of the project proceeded at a rapid pace. Wind-tunnel research, studies by prospective subcontractors and vendors, the joint participation of key NASA and other government installations, and early design studies by the eventual prime contractor all helped to facilitate the design effort and make possible the early availability of test hardware.

Based on the total Mercury experience, one of the underlying principles during the initial design period should be an emphasis placed on "designing for operation." For example, one of the lessons learned was that the instrumentation system should be designed with mission flexibility as a guide, such that, in the later phases of the program, new instrumentation requirements can be handled with a minimum of complication. In still another area, it was learned that component accessibility can be extremely important where schedule demands become critical. Certain time-critical systems and short-life components must be easily accessible in order to minimize the degree of disturbance to other systems and the time required to replace these types of units. Because of the weight and volume constraints, this concept could not faithfully be applied in the design evolution of the Mercury spacecraft, and significant penalties have been experienced whenever items needed to be removed under a tight schedule. It was learned in Mercury that all systems requiring manual operation by the astronaut must be designed with the limitations of the cabin volume (see fig. 3–3), suit mobility, and weightlessness in mind.

### Development and Qualification

As in any development program, one of the original ground rules at the outset of Project Mercury was to conduct a logical and progressive test program. This concept was closely maintained from the beginning of the project through the flight of Astronaut Cooper last May. Success in certain phases of this test progression has made possible the elimination of certain backup or follow-on flights. Since the time that Mercury was initially conceived, literally thousands of individual tests have been conducted in which test articles were used in all forms from components to full-scale spacecraft and under all combinations of real and simu-

lated operating conditions. For example, during the 1-year period from November 1959, about 10 months after the prime contract was awarded, to November 1960, some 270 hours were spent in testing the environmental control system in the altitude chamber, with a man wearing a pressure suit in the chamber to load the circuit more realistically. Early in 1961, further tests were conducted, often using astronauts, in the centrifuge to qualify the environmental system under acceleration loads.

For convenience, the spacecraft-system testing can be grouped into ground tests and flight tests of special test articles. The ground tests, in turn, can be categorized into areas of research, design, development, qualification, acceptance, and checkout. The discussion of development flight tests, which will be restricted to those using other than production spacecraft, consists of research studies, development tests, and qualification programs. The performance of the production spacecraft will be discussed in a later section of this paper. It is interesting to note that because of the rapid pace dictated by the high priority of the program, many of the individual test programs were conducted concurrently. This technique involved some risk, since, had a major problem developed, the expense in both time and money could have been considerable. The following paragraphs relate the more salient lessons learned during the formal Mercury development and qualification test program.

### Ground Testing

The research tests included those which attempted to verify design theories or sought new methods for accomplishing a given design task, whether it was a structural assembly, a heat-protection system, or improved methods of instrumenting the spacecraft and its crew. Hundreds of tests of this type, particularly those conducted in the wind tunnel, were car-

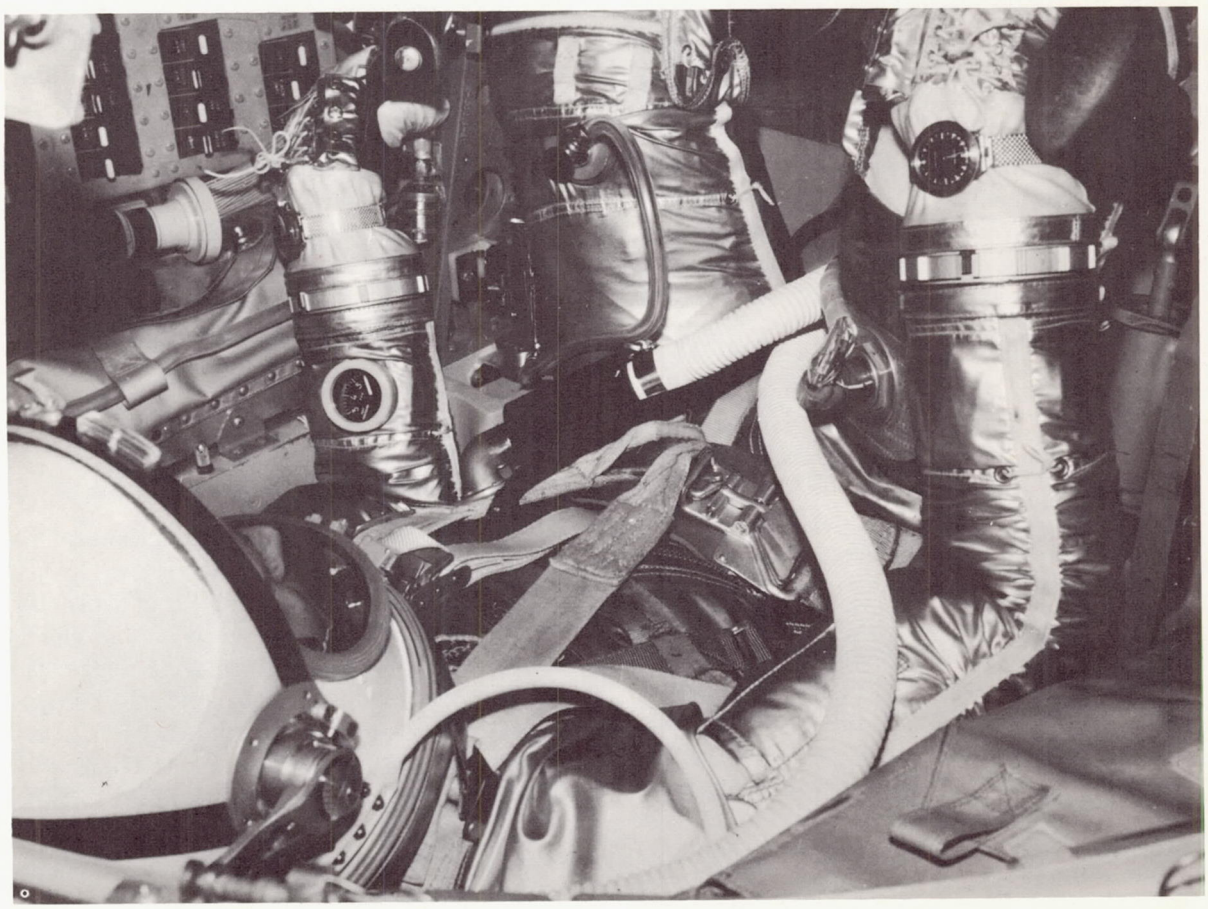


FIGURE 3–3.—Photograph of spacecraft interior.

ried out in the early phases of the Mercury effort at many of the NASA centers and at the contractor's plant. These tests will always be required when a new flight spectrum in a relatively unknown operational environment is penetrated, as it was in Mercury. It was tests of this kind which established the basic Mercury configuration, a shape which has already been projected into more advanced manned space programs.

The design testing, exemplified by the breadboard layouts in the case of electrical and sequential circuitry, was conducted jointly by the NASA and the contractor. This effort made possible the proof testing concurrent with initial design studies. Many thousands of tests were conducted, such as those in the design of the spacecraft-control-system thrust chambers, once the initial concept had been established.

When the basic design concept had evolved to a working hardware item, development testing served to expose this concept in the laboratory to the many combinations of operational and environmental conditions expected in space. Development testing was naturally hampered by the fact that weightlessness, a prime example, could not be adequately simulated on the ground; and this very deficiency resulted in an ineffective design for the water separation device of the environmental control system. The development of Mercury systems was a continuing program through the final mission and was aimed at mission flexibility, even after the spacecraft had been basically qualified for manned orbital operation. It was during the development testing that facets of the design which pertain to all aspects of its use were most evident, including the design-for-operation standards. It is in this testing area that engineering mock-ups have proved to be extremely valuable. In the case of the landing system, drop tests of boilerplate spacecraft were made to develop the landing-system deployment sequence and operation. Tests were made in the altitude chamber to verify that systems could operate for their required life cycle under realistic conditions. In essence, the development-test phase provided a means of validating the design concept and proving its intended reliability features.

Qualification testing conducted on the ground can further impose realistic operational conditions on a test article in various combinations for the specific purpose of verifying its reliable operation for inclusion as a final flight article. That is, there can and should be more than one type of qualification program for a given component, subsystem, or system, but these programs should become progressively more demanding on the capability of the hardware. In this testing area, adherence to prescribed test criteria must be rigorously enforced. The various combinations of qualification tests can be grouped into environmental tests, load tests, and performance tests with each of these groups having a specific purpose. Sometimes, the test conditions are not realistic enough or are not sufficiently demanding to reveal system weaknesses. During Mercury, for some of the subsystems, it was not until the actual unmanned flights that a system could be fully qualified for manned operation. For example, the launch-escape tower was subjected to all expected environmental conditions, an exhaustive series of load tests, and the operational situations associated with the launch-escape-system performance tests. Yet in the actual qualification flight program the heating loads on the truss structure of the tower were found to be more critical than had been calculated. Ground qualification is relatively inexpensive compared with full-scale flight qualification, and any system discrepancies which can be revealed in this phase will yield rewards in terms of time and expenditures later on. For example, during an early qualification test, it was found that the original igniters in the retrorocket motors would sometimes fail and blow out through the rocket nozzle before the main propellant grain had been ignited. New igniters, actually miniature solid rockets, were substituted for the original igniters. Had this system characteristic been overlooked through the manned orbital flights, the consequences could have been catastrophic. For flight-acceptance tests on units scheduled to be installed in flight vehicles, however, it was found that care should be taken not to over-test the article to the point at which its useful lifetime is approached or exceeded. During qualification testing, one must be assured that the unit being tested is not a "handmade" article and that, later on, a similar production version will not fail because it does not have the same ability to withstand the test-

ing environment. Of course, a critical requirement for the qualification program is that the test conditions imposed on the hardware exceed those expected to be present in the design environment in order to provide a safe margin for manufacturing deviations and unanticipated design weaknesses. It was found in Mercury that no single qualification criterion necessarily applies to all systems, and local operating conditions must be evaluated specifically for each system to insure that they are adequately accounted for in the qualification test environment.

It was learned in Mercury that, whenever a significant design change is to be incorporated into the spacecraft, a new hardware qualification program should be initiated to requalify major systems. Approximately 1,000 hours of test time were accumulated on a full-scale spacecraft in a program called "Project Orbit" which was conducted in a vacuum-thermal facility to insure that, during the orbital flight program, systems would maintain their previously demonstrated performance. As an example, when the spacecraft thruster assemblies were modified as discussed in this paper, the modified assemblies were tested in a vacuum chamber as part of the Project Orbit testing. These tests, using hydrogen peroxide, were made to determine if exposure to combined temperatures and low pressures for the expected duration of the mission would have adverse effects on the operation of the thruster assemblies. It was found to be most effective if actual operating conditions and procedures, including preflight checkout tests, could be realistically simulated in order to expose hardware to a complete operating cycle. Since system qualification and operating reliability are so closely related, the reader is referred to the paper entitled "Reliability and Flight Safety" for additional details.

Finally, the acceptance and checkout tests which are conducted by using actual flight hardware involve the same recommendations previously mentioned, those of avoiding overtesting, realistic operational test conditions, and thoroughness. It was learned in Mercury that, if tests of this type are conducted at multiple stations across the country by separate groups, the test procedures must be consistent if the test results are to be comparable. It is essential to repeat a system checkout if the system has been disturbed for any reason, such as the removal of another system where a definite interface exists. The acceptance and checkout aspect of ground testing is more thoroughly discussed in the paper entitled "Spacecraft Preflight Preparation."

### Flight Testing

This brief discussion of the development flight phase of Mercury will be limited to those flights where specially configured test vehicle (boilerplate spacecraft) were employed. Because the experiences gained by flights of production spacecraft are of more operational significance, they will be presented in the next section, Systems Performance. The flight-test program began with a number of tests in which spacecraft models were flown by using small multistage rockets. These tests provided preliminary data on the aerodynamic properties of the chosen external configuration. Almost concurrently with these flights, tests of the parachute systems were staged in which boilerplate spacecraft were dropped from cargo aircraft. These "drop tests" were initiated as an important step in the early design and development of the landing system. Specifically, the drogue parachute was developed by utilizing a weighted pod, which was dropped from an aircraft at high altitude. Other early flight tests included off-the-pad, or beach, aborts to develop the launch-escape system. In 1959, a reentry flight was conducted in which a specially designed and instrumented spacecraft and an Atlas launch vehicle were used to provide aerodynamic-heating data in the real flight spectrum. This flight, termed "Big Joe," was the first test in Mercury in which the Atlas was used. It was as a result of the data derived during this flight that the shingles initially on the spacecraft cylindrical section were replaced with somewhat thicker shingles made of beryllium to provide for more effective heat protection. The final series of early flight tests used the solid-propellant Little Joe vehicle (shown in fig. 3–4) to test the launch-escape system concept at critical inflight abort condition. Although most of the early flight tests were of a developmental nature, their missions served to qualify critical flight systems for later, more demanding flight tests. The intermediate series of aircraft drop tests, for instance, was com-

pleted to qualify the parachute and landing-shock attenuation systems. During this test phase in Mercury, valuable system improvements were incorporated at a minimum of cost and time.

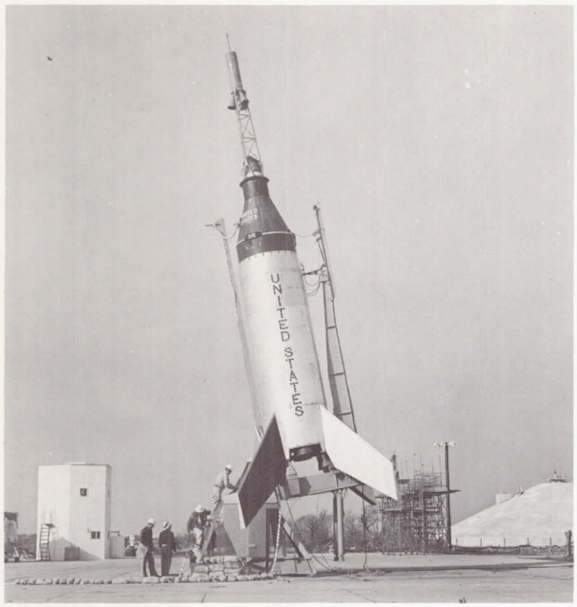



FIGURE 3–4.—Mercury Little-Joe launch-vehicle configuration.

### Weight Growth

A critical problem which was present throughout the Mercury program was that of weight growth. This problem, which seems to be characteristic of any development program where high performance and reliability are required, almost defies the steps taken to control weight. Figure 3–5 depicts the weight chronology of the spacecraft's orbital configuration. The maximum growth in weight was approximately 10 pounds per week in the very early phases of the program, but this figure was reduced to less than 2 pounds per week, or approximately ½ percent, at the final stage of the program. The launch weight of Astronaut Cooper's spacecraft, *Faith 7*, was some 700 pounds greater than the original design weight, despite repeated design reviews and other continuing weight controls. The lesson here is that proper planning must account for the inevitable weight growth in the design and development of high-performance spacecraft, since the consequences of not planning for it are either a degradation of the performance goals or exceeding the capability of the launch vehicle with its attendant delays.

### Attention to Detail

One of the most significant lessons learned from the Mercury program was the need for a careful and continuing attention to quality and engineering detail in all phases of the program. The spacecraft is made up of many individual systems and components to form a complex entity, and only through a close monitoring of the design and development of each piece of hardware and its relationship to all other associated components is it possible to recognize and correct problems rapidly before a costly failure occurs. Many performance discrepancies could not be anticipated because of the lack of experience or the inability to simulate adequately realistic conditions in the early test program. Later tests, however, were established to reveal these anomalies with a minimum of cost and delay. Although somewhat limited by the lack of experience, attention to detail during the design phase resulted in the incorporation of sys-

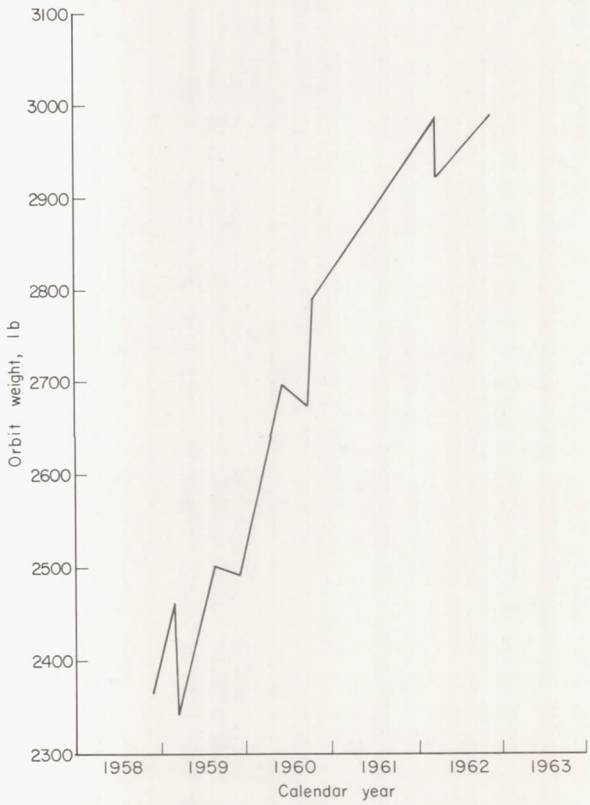



FIGURE 3–5.—Weight chronology for Mercury specification spacecraft.

tem redundancy, where a direct relationship to mission success existed.

As a prime example of the attention given to the incorporation of redundancy in the detailed design of critical spacecraft components, the actuation system of the launch-escape-tower clamp ring was backed up in nearly every component because of the serious consequences that would have resulted from a failure of the escape tower to jettison. In this system, the clamp ring is assembled at three points on its periphery, with each point being held by a dual explosive unit. Five of these six pyrotechnic units were ignited by an electrical squib, whereas the sixth was actuated by a percussion cap. Each of the electrical units incorporated a dual bridgewire. The automatic sequence was designed to send electrical signals from one power source to six of the bridgewires, with another but independent electrical supply for the remaining four bridgewires. Should the automatic relay fail, the astronaut was provided with a manual pull-ring which would energize the same jettison relay and also operate a gas generator to initiate the percussion cap, such that, in the event of failure in both the circuit to the sequencing relay and the two separate electrical power buses, the percussion cap would ignite. Actuation of any one of the six pyrotechnic explosive bolts was sufficient to effect proper separation of the escape tower from the spacecraft. The pyrotechnic circuit for the spacecraft-launch-vehicle adapter clamp ring was operated in a nearly identical manner.

During the development phase, an adherence to test specifications was maintained through a continued scrutiny of detailed performance results as they became available. Throughout the manned flights, attention to detail was necessary for an early recognition of possible problem areas, provided a means of responding to suggested action items, and precluded the occurrence of some system failures which ordinarily would have caused launch postponements and possibly a catastrophe.

### Systems Performance

During the design of the Mercury spacecraft, one of the most important considerations was that, should individual components or even entire systems fail, some means would exist either to complete the mission safely or to conduct a successful mission abort so that crew safety would be maintained. A summary of the flight-program objectives and results for the full-scale spacecraft is given in table 3–I. Of primary significance in the table is the fact that during the manned flight phase, all major systems operated satisfactorily, although on three of these missions, the astronaut was required, because of improper operation of the automatic control system, to conduct the retrofire maneuver manually. There were system malfunctions and performance discrepancies in each of these flights, but they were of such a nature that either a backup system or astronaut could circumvent the anomaly or that the failure of a component, such as an instrumentation sensor, was not critical to mission success. The system experience during the flight program was characterized by a number of isolated component anomalies, rather than a critical failure of such magnitude that a catastrophe resulted. This system development, accounting for system malfunctions and performance discrepancies, the action taken to correct them, and the steps required to increase system capability for the extended flight of Astronaut Cooper, is discussed in the following paragraphs. Since system anomalies are discussed specifically as they pertain to the continuing development of the major spacecraft systems, references 5, 6, 8, and 10 should be consulted for a more detailed performance discussion. Although random failures and system deficiencies are mentioned briefly herein, the greater emphasis is placed on system performance as it relates to design experience and the lessons which can be derived from actual operation of the systems in the space environment. Throughout the flight program, with the exception of the MA–9 mission, no changes were required specifically to accommodate a longer flight duration. The modifications made to the *Faith 7* (MA–9) spacecraft including those incorporated to make possible the extended flight period are summarized in table 3–II. Each major spacecraft system will be discussed separately, as in previous reports on the individual manned flights (refs. 5, 8, and 10).

### Heat Protection System

The heat protection system performed satisfactorily throughout the entire program and essentially as designed.

Some cracking and slight delamination of the ablation heat shield following reentry have been experienced on certain flights, but this occurrence has been of no real consequence. It was established that this minor delamination did not occur during the reentry heating period and probably resulted from the shock sustained at landing. Since the flotation attitude depends somewhat on the heat-shield weight, a slight modification was made to the *Faith 7* spacecraft to provide for retention of any small portions which might possibly have broken away after touchdown. It has always been desirable to achieve the most upright position in the water to facilitate astronaut egress.

Temperature measurements were made at various depths in the ablation shields for the orbital flights, and the maximum values experienced during reentry are summarized in figure 3–6 for each flight. The measurements showed good agreement with predicted values and were satisfactory.

### Mechanical and Pyrotechnic Systems

The mechanical and pyrotechnic systems consist of the separation devices, the landing system, the rocket motors, and the internal spacecraft structure. Each of the systems in this group is discussed separately.

There have been only minor problems with the separation devices. The primary separation planes (shown in fig. 3–7) are those between the launch-escape tower and the spacecraft cylindrical section, between the spacecraft and the launch vehicle, at the heat shield, and at the spacecraft hatch. In three of the earlier unmanned qualification flights, some difficulty was experienced in separating the spacecraft-adapter umbilicals, but postflight examinations showed that the pyrotechnic charges ignited satisfactorily. Further investigation revealed, however, that aerodynamic loads during clamp-ring separation had caused the clamp-ring segments to damage the umbilicals. A minor redesign of the clamp-ring cover which protects these separation devices eliminated the problem. In the Mercury-Redstone 4 (MR–4) mission, the explosively actuated side hatch, incorporated for the first time for this flight, was prematurely released. The astronaut egressed rapidly through the open hatch, and the spacecraft subsequently took on sea water and sank before recovery could be effected. A postflight investigation involving a thorough analysis and exhaustive testing was conducted, but the cause of the malfunction has never been established. However, the landing and recovery procedures were altered for succeeding missions to minimize the possibility of this malfunction recurring. The only other performance anomaly with regard to separation devices occurred in the recent flight of Astronaut Cooper. Here,

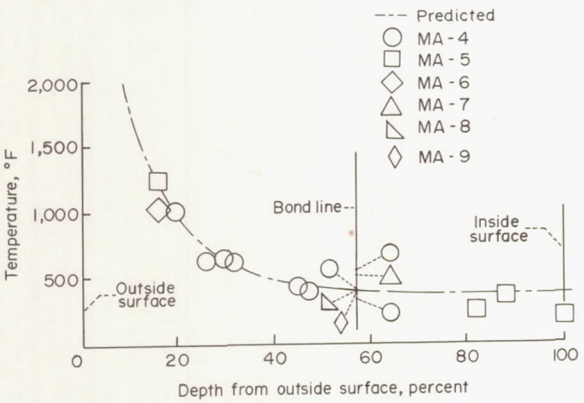



FIGURE 3–6.—Ablation shield maximum temperatures.

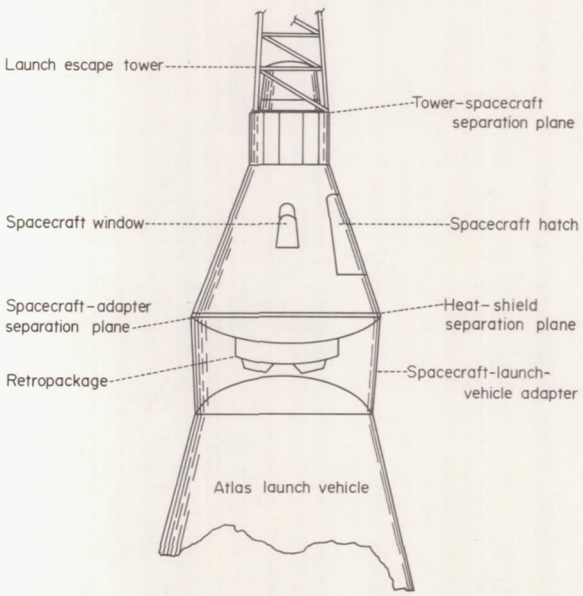



FIGURE 3–7.—Major spacecraft separation planes.

*Table 3–I.—Mercury Flight Program Summary*

| Mission [a] | Spacecraft [b] | Launch date | Flight duration [c], hr:min:sec | Occupant | Basic test objectives [d] | Summary of results [e] |
|---|---|---|---|---|---|---|
| LJ–1 | BP | Aug. 21, 1959 | 00:00:20 | | Max. dynamic pressure abort; evaluate launch escape and recovery systems. | Object. not met; inadvertent abort initiated during countdown. |
| Big Joe | BP | Sept. 9, 1959 | 00:13:00 | | Ballistic flight; evaluate heat-protection concept, aerodynamic shape, and recovery system. | Successful. |
| LJ–6 | BP | Oct. 4, 1959 | 00:05:10 | | Ballistic flight; qualify launch-vehicle structure; evaluate command system. | Successful. |
| LJ–1A | BP | Nov. 4, 1959 | 00:08:11 | | Max. dynamic pressure abort; same as LJ–1. | Primary object. not met; escape motor ignition was late during reduced pressure region. |
| LJ–2 | BP | Dec. 4, 1959 | 00:11:06 | Rhesus monkey | High-altitude abort; evaluate launch, abort, and reentry dynamics on S/C; recovery. | Successful. |
| LJ–1B | BP | Jan. 21, 1960 | 00:08:35 | Rhesus monkey | Max. dynamic pressure abort; same as LJ–1A; evaluate launch and abort. | Successful. |
| Beach abort | S/C 1 | May 9, 1960 | 00:01:16 | | Off-the-pad abort; qualify structure and launch escape system for simulated pad abort. | Successful; expended rocket motor and tower not separated as quickly as expected. |
| MA–1 | S/C 4 | July 29, 1960 | 00:03:18 | | Ballistic flight; S/C-launch-vehicle compatibility; thermal loads in critical abort. | Object. not met; mission failed at about 60 sec after lift-off; S/C not recovered. |
| LJ–5 | S/C 3 | Nov. 8, 1960 | 00:02:22 | | Max. dynamic pressure abort; qualify launch escape system and structure. | Object. not met; S/C did not separate from launch vehicle. |
| MR–1 | S/C 2 | Nov. 21, 1960 | 00:00:00 | Simulated man | Suborbital flight; qualify S/C-launch-vehicle compatibility, posigrades, ASCS. | Test object. not met; launch vehicle shutdown at lift-off; S/C landing system correctly deployed. |
| MR–1A | S/C 2 | Dec. 19, 1960 | 00:15:45 | Simulated man | Suborbital flight; same as MR–1 | Successful; cutoff overspeed caused overshoot. |
| MR–2 | S/C 5 | Feb. 21, 1960 | 00:16:39 | Chimpanzee | Suborbital flight; qualify ECS, landing bag. | Successful; launch vehicle failed to shutdown until fuel depletion, S/C overshot by 130 miles. |
| MA–2 | S/C 6 | Feb. 21, 1961 | 00:17:56 | | Ballistic flight; same as MA–1 | Successful. |
| LJ–5A | S/C 14 | Mar. 18, 1961 | 00:23:48 | | Max. dynamic pressure abort; same as LJ–5. | Object. not met; escape rocket ignited early; S/C recovered intact. |

| | | | | | | |
|---|---|---|---|---|---|---|
| MR–BD | BP | Mar. 24, 1961 | 00:08:23 | | Suborbital flight; evaluate modifications to correct MR–1 and MR–2 malfunctions. | Successful. |
| MA–3 | S/C 8 | Apr. 25, 1961 | 00:07:19 | Simulated man | One-pass orbital flight; evaluate all S/C systems, network, recovery forces. | Object. not met; launch vehicle failed to follow roll program; S/C escape system operated. |
| LJ–5B | S/C 14A | Apr. 28, 1961 | 00:05:25 | | Max. dynamic pressure abort; same as LJ–5 and LJ–5A. | Successful. |
| MR–3 | S/C 7 | May 5, 1961 | 00:15:22 | Alan B. Shepard | Suborbital flight; familiarize man with space flight; evaluate response and S/C control. | Successful; first American astronaut in space. |
| MR–4 | S/C 11 | July 21, 1961 | 00:15:37 | Virgil I. Grissom. | Suborbital flight; same as MR–3 | Successful; premature hatch release caused S/C to take on water and sink; astronaut recovered. |
| MA–4 | S/C 8A | Sept. 13, 1961 | 01:49:20 | Simulated man | One-pass orbital flight; same as MA–3. | Successful; open circuit in control system caused S/C to land 75 miles uprange; S/C recovered. |
| MA–5 | S/C 9 | Nov. 29, 1961 | 03:20:59 | Chimpanzee | Three-pass orbital flight; qualify all systems, network, for orbital flight recovery. | Successful; control system malfunction terminated flight after two passes. |
| MA–6 | S/C 13 | Feb. 20, 1962 | 04:55:23 | John H. Glenn, Jr. | Three-pass orbital flight; evaluate effects on and performance of astronaut in space; astronaut's evaluation of S/C and support. | Successful; first American to orbit earth; control system malfunction required manual retrofire and reentry; erroneous T/M signal, retropack retained through reentry; S/C landed 40 miles uprange. |
| MA–7 | S/C 18 | May 24, 1962 | 04:56:05 | M. Scott Carpenter. | Three-pass orbital flight; same as MA–6; evaluate S/C modifications and network. | Successful; horizon scanner circuit malfunction required manual retrofire; yaw error caused S/C to land 250 miles downrange, recovery in 3 hr. |
| MA–8 | S/C 16 | Oct. 3, 1962 | 09:13:11 | Walter M. Schirra, Jr. | Six-pass orbital flight; same as MA–6 and MA–7 except for extended duration. | Successful; partially blocked ECS coolant valve delayed stabilizing suit temperature until 2nd pass; S/C landed 4½ miles from primary recovery ship. |
| MA–9 | S/C 20 | May 15, 1963 | 34:19:49 | L. Gordon Cooper, Jr. | Twenty-two pass orbital flight; evaluate effects on man of up to 1 day in space; verify man as primary S/C system. | Successful; short circuit late in flight disabled ASCS, inverters, prompted manual retrofire and reentry; S/C landed 4½ miles from ship. |

[a] LJ—Little Joe launch vehicle mission; MA—Mercury-Atlas (launch vehicle) mission; MR—Mercury-Redstone (launch vehicle) mission; BD—Booster development.

[b] BP—Boilerplate spacecraft; S/C—spacecraft; S/C 10, 12, 15, 17, 19 not used in flight program.

[c] Duration measured from lift-off to landing.

[d] ASCS—automatic stabilization and control systems; ECS—environmental control system.

[e] Object.—objectives of flight; prop.—propellant; T/M—telemetry.

*Table 3–II.—Summary of Modifications to MA–9 Spacecraft*

| System | Modification | Justification |
|---|---|---|
| Spacecraft control system. | 1. Removed rate control system (RSCS)<br>2. Added 15-pound-capacity fuel tank<br>3. Installed modified 1- and 6-pound thrust chambers<br>4. Installed interconnect valve | 1. Not necessary; reduced weight by 12 lb<br>2. Additional control capability [a]<br>3. Improved reliability and operating characteristics<br>4. Improved control-fuel management |
| Communications systems. | 1. Removed backup UHF voice transmitter<br>2. Installed slow-scan television unit | 1. Primary unit reliable, reduced weight by 3 lb<br>2. Inflight evaluation of TV for ground monitoring of astronaut and instruments |
| Instrumentation system. | 1. Deleted backup telemetry transmitter<br>2. Changed recorder speed from 1⅞ ips to 1⅝16 ips and programed<br>3. Deleted periscope<br>4. Deleted low-level commutator | 1. Primary unit reliable, reduced weight by 2 lb<br>2. Greater flight coverage necessary without changing recorder or reel size<br>3. Reduce weight by 76 lb; unnecessary for attitude reference<br>4. Served its purpose on previous flights |
| Life support systems | 1. Added 4 lb of breathing oxygen<br>2. Installed parallel suit-coolant control valve<br>3. Added inline condensate trap<br>4. Added urine and condensate transfer systems with manual operation<br>5. Added 9 lb of cooling water<br>6. Added 4.5 lb of drinking water<br>7. Added 0.8 lb of $CO^2$ adsorber | 1. Necessary for extended mission<br>2. Added reliability in case of partial valve blockage as experienced in MA–8<br>3. Existing condensate system believed ineffective<br>4. Increase urine and condensate storage capability because of extended mission<br>5. Increase cooling capability because of mission<br>6. Necessary for increased mission duration<br>7. Necessary for increased mission duration |
| Electrical and sequential systems. | 1. Replaced two 1,500 watt-hour batteries with two 3,000 watt-hour units<br>2. Replaced two of three inverters | 1. Necessary for extended flight duration<br>2. Improved thermal and operating properties |

[a]Tank intentionally serviced to only 10 lb. of fuel.

four of the five umbilicals, two between the spacecraft and the adapter and three between the spacecraft and the retropackage (fig. 3–8) failed to separate in a normal manner. Later analysis revealed that each of the malfunctioned disconnects (see fig. 3–9), which normally contained a dual charge came from a special test lot which did not contain the main charge of explosive powder. Somehow, this lot had been improperly marked as intended for flight hardware. The umbilical which separated normally contained the intended amount of explosive and came from a properly identified lot. The four umbilicals which failed to separate pyrotechnically were released through actuation of a backup mechanical device. This experience points up the necessity for close control of flight articles and a means for establishing that the hardware intended for flight satisfies prescribed specifications.

The landing system, which includes the main, reserve, and drogue-stabilization parachutes and the landing-shock attenuation system (landing bag), has never failed in flight during the production-spacecraft flight program. In the second Mercury-Redstone mission, the heat shield was lost after landing because the metal retaining straps and landing-bag material to

which the shield was attached failed as a result of wave action and strengthening of existing straps for later spacecraft eliminated this problem. The only other anomalies in the operation of the landing system were concerned with the altitude of parachute deployment, and these anomalies are discussed in the Electrical and Sequential Systems section. The successful performance of the landing system, particularly the parachutes, can be attributed to a thorough test program involving some 80 air drops of full-scale spacecraft.




FIGURE 3–8.—Spacecraft photograph displaying retrorocket umbilicals.

The rocket motors include the launch-escape motor, the retrorockets, the posigrade rockets, and the launch-escape-tower jettison motor. All of the rocket motors used solid propellants, and their nominal thrust values are indicated in table 3–III. Each of these rocket systems has operated satisfactorily throughout the Mercury flight program. It was found early in the program that the launch-escape tower did not separate rapidly enough from the spacecraft after an off-the-pad abort test because of thrust impingement on the tower; therefore, the tower-jettison rocket-nozzle configuration was subsequently changed from a one- to a three-nozzle arrangement. Because of reliable launch-vehicle operation, the launch-escape system was never needed for an atmospheric abort during the manned flight program, and the large escape motor successfully ignited each time when the system was normally jettisoned. An abort, however, occurred during the unmanned MA–3 mission, and the system operated satisfactorily.

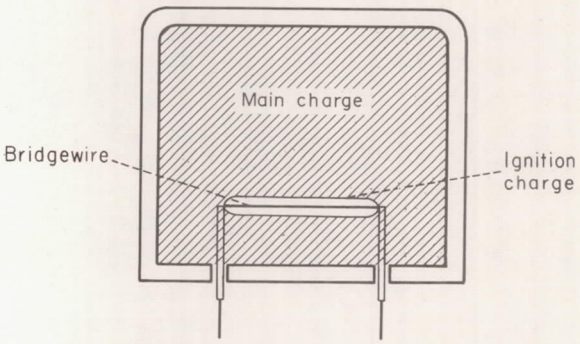



FIGURE 3–9.—Schematic diagram of explosive umbilical disconnects.

*Table 3–III.—Nominal Rocket Motor Characteristics*

| Rocket motor | Number of motors | Nominal thrust each, lb | Approximate burning time each, sec |
|---|---|---|---|
| Escape | 1 | 52, 000 | 1 |
| Tower jettison | 1 | 800 | 1. 5 |
| Posigrade | 3 | 400 | 1 |
| Retrograde | 3 | 1, 000 | 10 |

The internal spacecraft structure has been compromised only once during a mission critical situation, a record which is essentially proved by the fact that water, following an ocean landing, had never entered the spacecraft in appreciable amounts, except in one instance, because of a structural failure. In the MR–2 mission following landing recontact of the heat shield with the large pressure bulkhead caused puncturing that resulted in a sizable leakage rate.

The spacecraft was recovered, however, within a safe period. During postflight inspections of all manned spacecraft, some evidence of recontact by the heat shield upon landing has been present, but this damage to the large pressure bulkhead has been slight. The integrity of the spacecraft's load-carrying structure was especially proven during the Little Joe flight program. In one of these flights, the late ignition of one of the Little Joe rocket motors caused the trajectory to be considerably flattened, and as a result the spacecraft was exposed to loading conditions approximately twice those expected for a normal flight.

#### Spacecraft Control System

The spacecraft control system provides for attitude control and rate stabilization of the spacecraft during the orbital and reentry phases. In addition to the system electronics, the spacecraft control system is composed of two independent reaction control systems (RCS), one of which supplied fuel for the automatic stabilization and control system (ASCS) and fly-by-wire (FBW) modes and the other which, until MA–9, supplied the manual proportional (MP) and the rate stabilization and control system (RSCS) modes. The RSCS unit was installed in the MR–4 and subsequent flights as a backup to one of the secondary modes of the ASCS, that of auxiliary damping. This unit was removed as unnecessary for the MA–9 flight, with major deciding factors being its high fuel-consumption characteristics and weight. The FBW and MP modes were available for direct manual control by the astronaut, initially as backups to the ASCS and in the final two orbital flights as modes of equal priority. Although the control system has operated adequately in all of the manned flights, largely because of the ability of the pilot to exercise precise attitude control manually, this system has exhibited failures of one type or another in nearly every flight. The one exception was the six-pass mission of Astronaut Schirra, in which the system operated correctly.

The single most prevalent malfunction in the control system during the early manned flight program was the intermittent failure of the small 1-pound thrust-chamber assemblies (thrusters). In addition, during a manned suborbital flight (MR–3) a 6-pound thruster also failed to produce thrust when required. During the MA–5 flight, the mission duration was terminated early because of a failure in the thrust chamber assembly. During the flight of Astronaut Glenn, intermittent failures of the 1-pound pitch and yaw thrusters would have caused a similar early termination of the mission had the pilot not been present to exercise his manual control option. Immediately following the first inflight thruster failures, a complete analysis was begun to determine the exact cause of the system discrepancy. In the postflight inspections for the MR–3, MA–5, and MA–6 spacecraft, small particles were discovered at critical points in the thrust chamber assembly, and for the MA–5 mission a large metal deposit which partially blocked the thruster orifice was found. Although thruster malfunctions were experienced during the MA–4 flight, the postflight inspection did not reveal any thruster valve contamination. The exact mechanism for transporting these particles, some of which were found to be broken pieces from the stainless-steel dutch-weave screens which distributed the flow, to upstream points is still unknown. Three steps were taken for the MA–7 mission to correct this anomaly, one being the replacement of the dutch-weave screens with a combination of a stainless-steel fuel distribution plate and platinum screens, another being the reduction of the bore and size of the heat barrier, and the third being the relocation of the fuel-metering orifice to the upstream side of the solenoid valve (ref. 8). While these changes constituted the MA–7 modification, a more refined design change was being developed and qualified in the Project Orbit altitude chamber tests. This configuration, compared in figure 3–10 with previous 1-pound thruster configurations, involved both the 1- and 6-pound thrusters and was installed in the MA–9 spacecraft. No thruster failures of this type occurred on either the MA–7, MA–8, or MA–9 flights after the modifications had been successively incorporated.

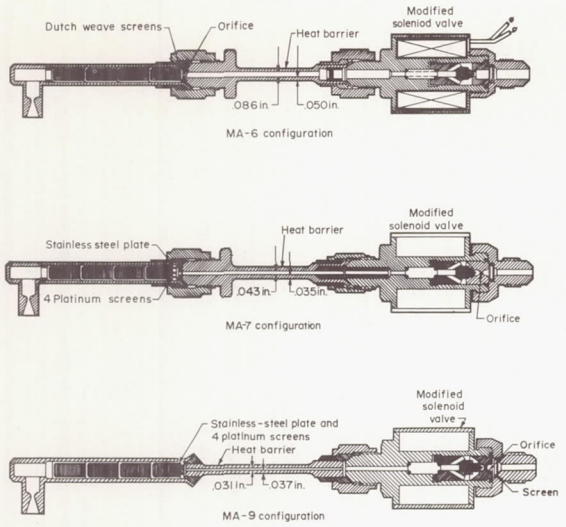



FIGURE 3–10.—Comparison of 1-pound thrust-chamber configurations.

The horizon scanners, which were used to provide an external reference for the attitude gyros, were a source of difficulty in the earlier orbital flights. In the MR–4 flight after tower jettisoning, the scanner was observed to be generating unexpected ignore signals, the cause of which was later traced to the impingement and heating effects caused by the ignition of the launch-escape rocket. A modification to the horizon-scanner cover eliminated this problem.

In the MA–4 flight, both scanners exhibited output variations which could not be correlated with attitude changes, and this anomaly was subsequently found to have been partially caused by "cold-cloud effects"; in addition, a shorted capacitor in the scanner circuit contributed to the attitude discrepancy. Since the scanner unit had been designed without accurately taking into account the effect of high-altitude cloud formations in the view field, a temporary modification of altering the bias levels was made for the MA–5 flight, but this change did not completely eliminate the problem. Further system refinement involving signal clipping for the earth portion of the view resulted in a successful modification for the first manned orbital flight. Since that time, only isolated occurrences of "cold-cloud effects" have been observed. During the MA–7 flight, a horizon-scanner circuit failure (see ref. 8) of another type occurred, but because the antenna canister was normally jettisoned prior to landing, it was impossible to conduct a post-flight inspection of the hardware and determine the cause of the failure. This malfunction, which occurred in the pitch scanner, is believed to have been random in nature within the scanner circuitry.

The only remaining control system problem of any consequence during the full-scale flight program was the existence of an open circuit in the pitch-rate gyro input to the amplifier-calibrator (Amp-Cal), or autopilot, during the MA–4 mission. The Amp-Cal is the electronic unit which generates automatic control system logic for the various ASCS operating modes. The partial loss of gyro information to the autopilot caused the spacecraft attitude to be in error at retrofire, which in turn resulted in the MA–4 spacecraft's landing some 75 nautical miles up range of the intended point. This malfunction was either not detected during preflight tests or it occurred during the flight.

Although the control system performed satisfactorily during Astronaut Cooper's mission, an electrical short circuit, which occurred at two of the power-carrying plugs into the autopilot and resulted in the loss of the automatic control mode during the final few orbital passes. However, because this malfunction occurred at this specific interface and is primarily of an electrical nature, it is discussed in a later paragraph under Electrical and Sequential Systems. Because of the loss of the automatic control mode during the retrofire and reentry flight maneuvers, the astronaut conducted these maneuvers by using both manual modes available to him.

The only other major modifications to the control system for the 1-day mission of Astronaut Cooper were the addition of a 15-pound-capacity fuel tank, which is shown in figure 3–11, and the incorporation of the interconnect valve between the two RCS systems for better fuel utilization, in an emergency, and for more effective fuel jettisoning.

#### Communications Systems

The original design configuration of the communications systems proved to have been the most conservative of all of the major systems. These systems—the voice transceivers, the radar beacons, the location aids, and the command receivers—operated satisfactorily throughout the

flight program. Because of the excellent performance of these systems, some of their backup units were deleted, including one of the two command receivers and decoders and the high-frequency (HF) recovery transceiver for the MA–8 and MA–9 flights and the ultra-high frequency (UHF) backup voice transceiver for the MA–9 flight. One of the two UHF telemetry transmitters, which were part of the instrumentation system, was also deleted as unnecessary for the MA–9 mission. A slow-scan television system, shown in figure 3–12, was included for evaluation aboard the *Faith 7* spacecraft, but the quality and usefulness of its transmissions were not satisfactory.

In the initial two manned orbital flights, it was noted that signals were not being received from the HF recovery transmitter, but because of the circumstances at the time of recovery and the uncertainty of HF reception in the landing area, it could not be established that an anomaly existed. However, when this discrepancy still existed on the MA–8 mission, attention was directed to the ineffectiveness of the HF recovery beacon. Careful analysis revealed that when the HF "whip" antenna was pyrotechnically deployed upon landing, the spacecraft was usually not completely erect in the water. The combination of the electrically conducting products of combustion from the explosive charge used to extend this antenna and the fact that it was extended under water are believed to be the cause of this communications anomaly. The antenna was subsequently deployed by using pressurized nitrogen gas, which is nonconductive, and it was programed such that deployment would not occur until the antenna was clear of the water. Reception from this beacon was satisfactory during the MA–9 mission.

For the MA–8 flight, a pair of more sensitive microphones was installed in the pilot's helmet, and the increased sensitivity apparently caused the background noise from the launch vehicle to trigger the voice-operated relay in the air-ground circuit. For the MA–9 mission, these microphones were modified to reduce background noise sensitivity such that this triggering action ceased.

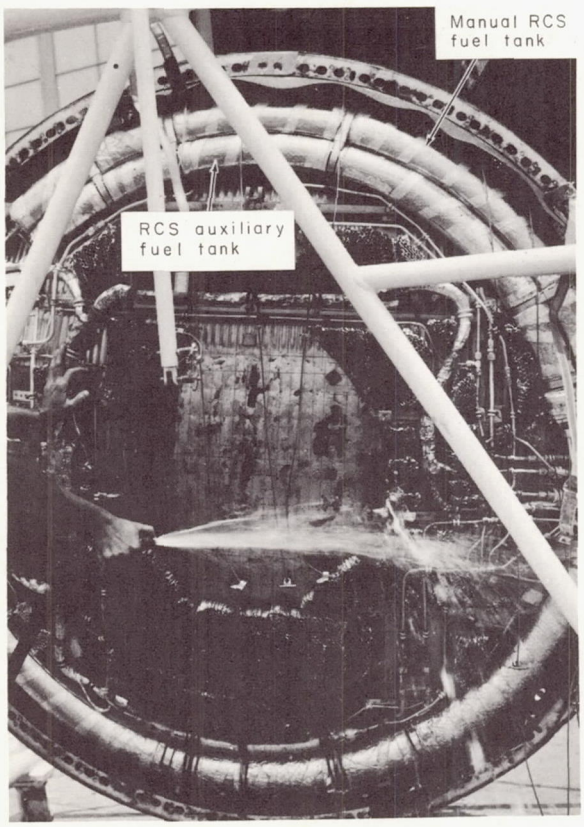



FIGURE 3–11.—Auxiliary reaction control system fuel tank.

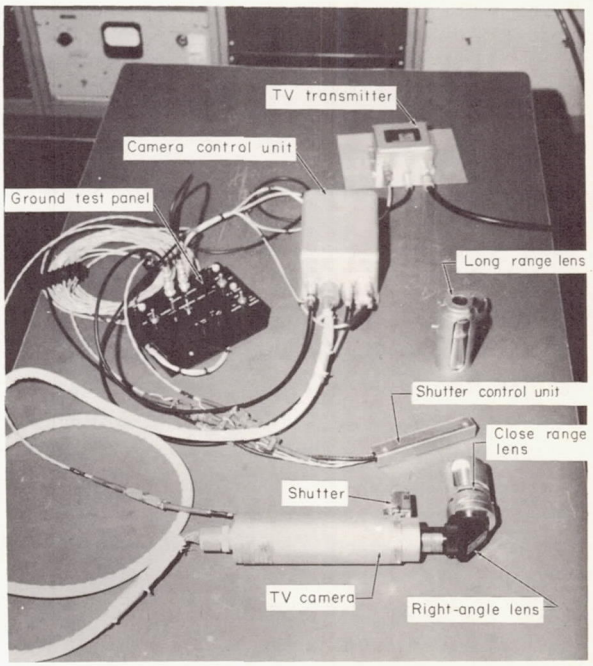



FIGURE 3–12.—Television system evaluated during MA–9.

Reports of reception of HF voice communications during the first three manned orbital flights were somewhat inconsistent with regard to quality, but the periods allowed for a complete inflight test of the HF voice equipment were also very brief. At any rate, because of reports that reception of HF voice signals during the first two manned orbital flights was unsatisfactory, a special HF antenna was installed on the retropackage for the MA–8 flight (see ref. 10). There were reports of excellent reception of signals from this antenna during the flight at ranges exceeding 2,000 nautical miles, while other reports stated that even when the spacecraft was nearly overhead, the reception was poor to unreadable. This inconsistency is not clearly understood, but the effects of spacecraft attitude at the time of transmission, the atmospheric propagation characteristics at the time of contact, and the status of operational ground equipment remain as unknown variables. A more closely controlled test of this special dipole antenna was conducted during the MA–9 flight, and it was fully successful. Although HF voice transmissions were heard during MA–8, the results of MA–9 were more consistent and indicated reliable operation. It might be mentioned that both the pilots and ground-control personnel preferred the UHF voice equipment to the HF system, particularly since none of the missions were such that nearly continuous communications were required. The UHF communications, of course, are limited to essentially line-of-sight ranges, but have signal-to-noise characteristics superior to those of HF in flight. However, the MA–9 astronaut found HF communications quite useful during the long periods in which he could not make UHF contact with a network station.

Although the command system has never been exercised for a commanded abort, its performance has been entirely satisfactory during other inflight exercises, such as the reception of signals for instrumentation calibration in all orbital flights and for an emergency voice communications test and a commanded wake-up tone in the MA–9 mission. For the unmanned orbital flights, MA–4 and MA–5, the command system was successfully used to control the operation of the spacecraft and bring it safely back from orbit.

### Instrumentation System

The instrumentation system monitored over 100 performance variables and events throughout the spacecraft, and the operation of this system was satisfactory throughout the entire Mercury program. The system was designed with enough flexibility to incorporate required instrumentation changes as the program progressed. In the manned orbital flight phase, it was desired to have a more complete temperature survey at discrete spacecraft points, primarily on the spacecraft afterbody; and a low-level commutator circuit was installed. This unit was deleted from the MA–9 spacecraft as having served its purpose and to save weight. The confidence in the telemetry transmitters through the third manned orbital flight led to a decision to eliminate one of the two redundant units from the *Faith 7* spacecraft to save weight. The onboard recording capacity for the MA–9 flight was extended by changing the tape speed from $1\frac{7}{8}$ inches per second (ips) to $1\frac{5}{16}$ ips and reprograming the operation periods such that only essential information was recorded during the expected 34-hour period.

Probably the most widely known system malfunction in the entire Mercury program is that associated with the failure of a limit switch which sensed heat-shield release. During the MA–6 mission, ground-control personnel received a telemetry signal which indicated that the heat shield had been prematurely unlatched from the spacecraft. Although it was believed that this signal was improper and involved an instrumentation failure, a decision was made to reenter with the retropackage attached to insure that the heat shield would not part from the spacecraft during the critical reentry heating period. A postflight examination of the instrumentation revealed that a limit switch had a bent and loose shaft (shown in fig. 3–13) and that manipulation of the sensor without appreciably displacing the sensing shaft would generate an erroneous signal. This experience prompted a change in the installation technique and a directive for tighter quality-control standards to insure that prescribed manufacturing tolerances would be maintained. This type of malfunction did not recur in subsequent flights.

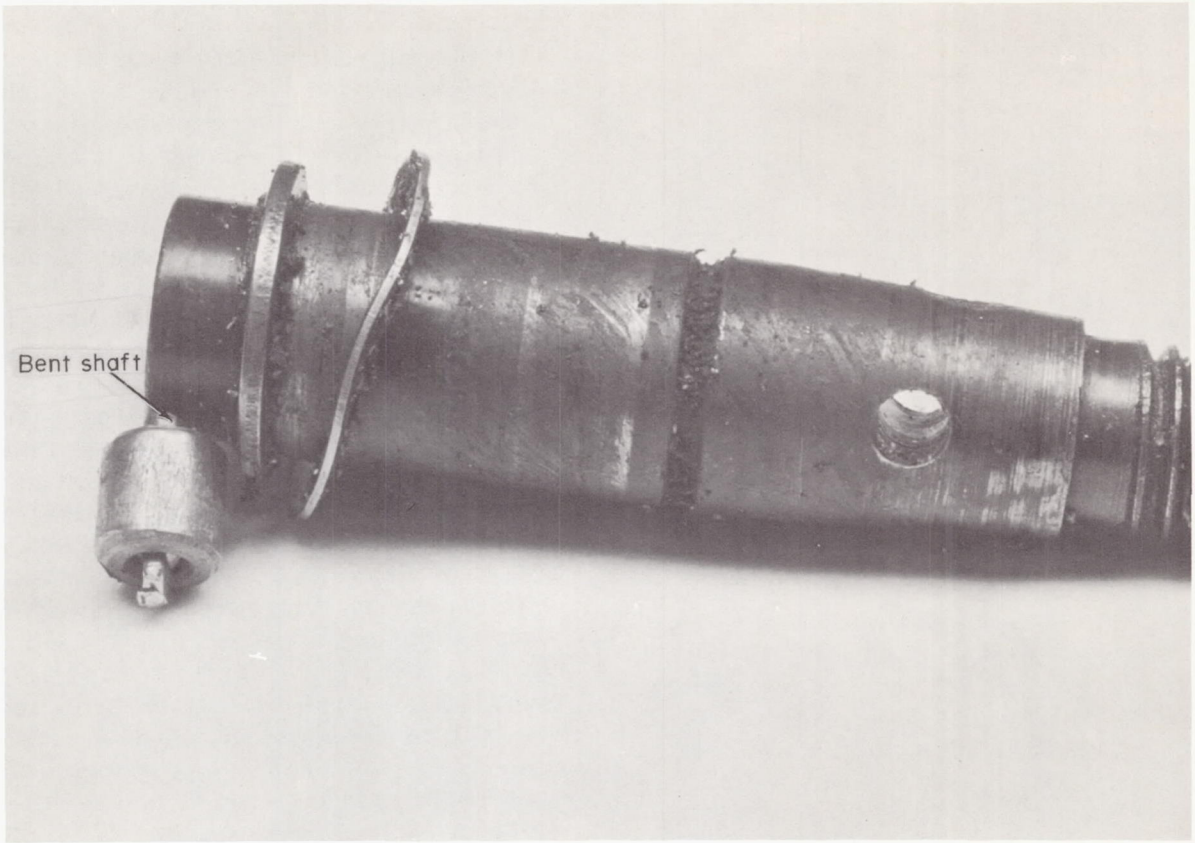



FIGURE 3-13.—MA-6 limit switch used to sense heat-shield release.

Early in the flight program, beginning with the Little Joe 5 mission, the mechanical spacecraft clock was found to be sensitive to accelerations in excess of 5g. An electronic digital clock was substituted for this unit and operated satisfactorily.

During the MA-7 mission, the blood-pressure measuring system (BPMS) yielded data which were of only marginal value. The system was thoroughly checked out following the flight, and no major system malfunction was found. It was shown, however, that proper techniques, including establishing a proper amplifier gain setting, correlation with clinically measured values, and the fitting of the pressure cuff to the individual flight astronaut, were not well understood. A thorough review of the entire system, its operating characteristics, and the preflight calibration procedures was conducted in the months after the MA-7 flight, and the data quality for the MA-8 and MA-9 missions was correspondingly improved and resulted in usable values. A discussion of this anomaly from a medical standpoint is presented in the Aeromedical Preparations paper.

During the MA-9 mission, the programer, which automatically controls the operation and sequence of events of certain spacecraft systems, exhibited two anomalies, one inherent and the other resulting from a structural failure. The inherent anomaly, evident to varying degrees in previous flights, involved a sensitive control circuit containing transistors which actuated power relays to operate the programer. This circuit was sensitive to certain input voltage transients which occasionally caused undesired programer operation. Prior to the MA-9 flight, a loading resistor had been added to reduce the inherent sensitivity, and an on-off switch had been incorporated so that the pilot could shut the system down if improper operation occurred. On two occasions, the unit was inadvertently triggered and continued to call for instrumentation calibrations, one of its programed functions. On both occasions, the

astronaut turned the system off, and no serious consequences resulted, but the need to improve system design for future programs in this area, particularly for transistorized circuits, is exemplified.

The other programer anomaly, although in a separate section of the system, involved the shearing of a pin used to maintain alinement of a gear in the programer drive mechanism. Figure 3–14 depicts the misalined gear, which resulted in an inflight binding of the programer and the preclusion of a significant portion of recorded data during the midpoint of the MA–9 flight until the astronaut switched from programed to continuous operation.

During the MA–9 flight, the respiration rate sensor failed to yield reliable data during and after the fifth orbital pass, but other sources of this information were found to be adequate.

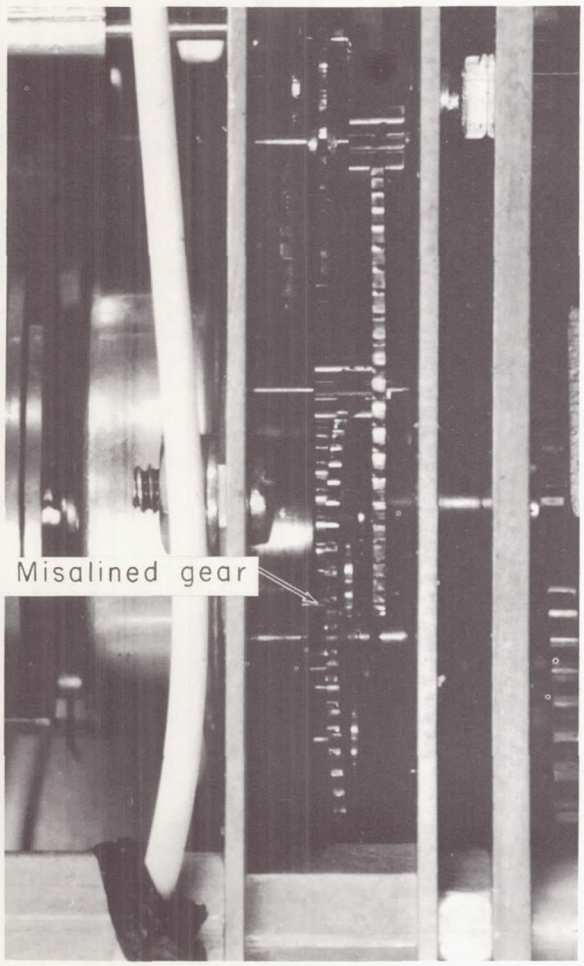



FIGURE 3–14.—Misalined gear in MA–9 programer.

A postflight investigation of the system disclosed a broken solder joint at the attachment point of the sensor lead.

### Life-Support Systems

The life-support systems primarily provide for control of the cabin and suit atmospheres, management of metabolic-waste products, and the supply of food and liquid for the astronaut. The major changes to the MA–9 life-support systems, including the environmental control system (ECS) (fig. 3–15), from those of previous missions were accomplished primarily in support of the increased mission time, and the most significant modifications were as follows:

(1) Addition of about 4 pounds of primary breathing oxygen ($O_2$), stored under pressure, for a nominal total of 12 pounds in the system.

(2) Increase in the carbon-dioxide ($CO_2$) adsorber, lithium hydroxide (LiOH), quantity from 4.6 to 5.4 pounds. The amount of activated charcoal, as the odor absorber, was decreased from 1.0 to 0.2 pound, which was sufficient.

(3) Increase in the stored coolant-system water from 39 pounds to 48 pounds.

(4) Increase in the capability of the urine collection and storage system.

(5) Addition of an improved condensate collection and storage system, including a new wick-type condensate trap (shown in fig. 3–16) to extract free water from the suit circuit of the ECS.

(6) Increase of the stored drinking water by 4.5 pounds for a total of 10 pounds of potable water.

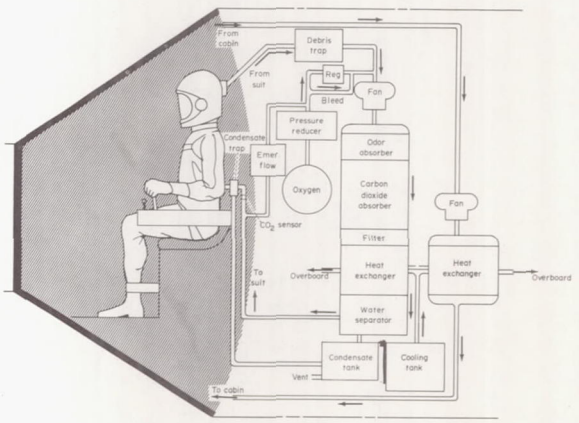
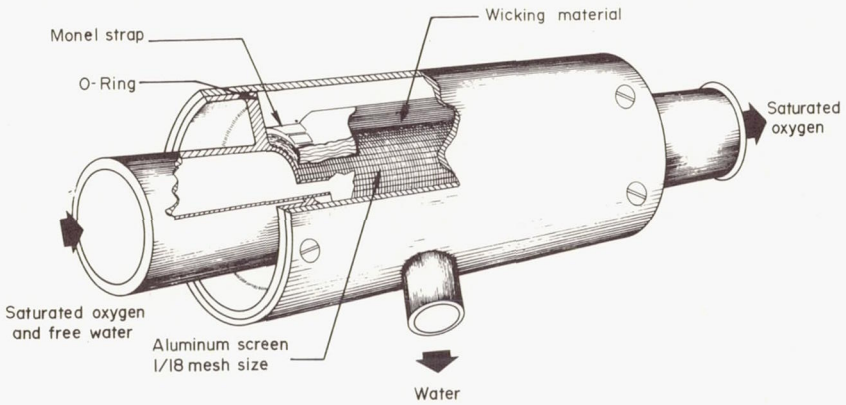
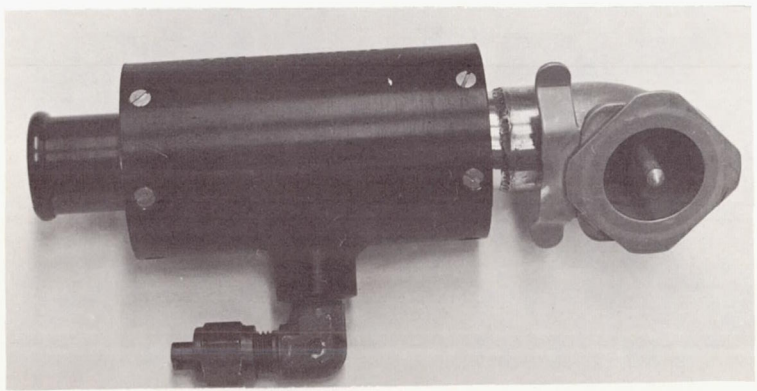


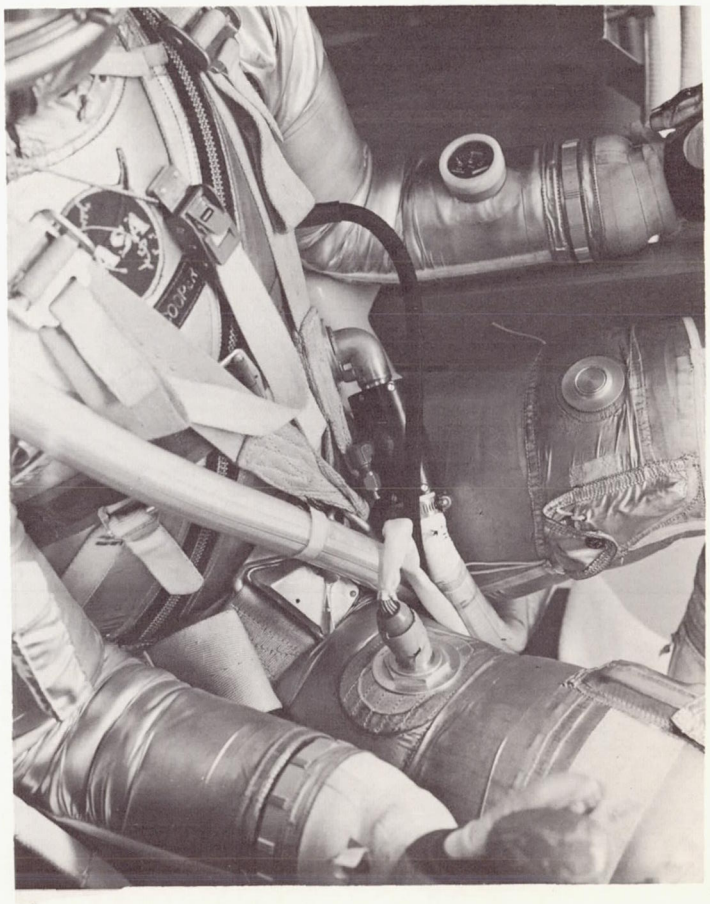

FIGURE 3–15.—Environmental control system schematic diagram.




(a) Condensate trap details



(b) Condensate trap



(c) Condensate trap installation

FIGURE 3–16.—MA–9 inline condensate trap.

A parallel coolant control valve (CCV) shown in the upper right corner of figure 3–17 was added in the suit cooling-water circuit for redundancy with the primary valve (top-left on the control plate) in the event of a serious valve blockage by contamination, which was experienced in the MA–8 mission.

The operation of the life-support equipment during the MA–8 mission was normal, except that the suit-circuit CCV was partially blocked by solidified lubricant and delayed the astronaut's stabilization of the cooling system at a comfortable level. Preflight procedures were changed for the MA–9 mission so that the CCV's were cleaned and properly lubricated prior to flight, but after the manned systems tests. The cooling water was also passed through a 0.15 micron filter before being transferred into the spacecraft. Blocking of the CCV during the MA–9 flight was not experienced. However, the astronaut was required to make a large number of minor changes to the suit CCV setting in an attempt to maintain the heat-exchanger dome temperature, which was the cooling system control parameter, within the desired range. No system deficiencies or hardware malfunctions were found during the postflight inspection or testing. It is a characteristic of the system that changes in metabolic and external suit-circuit heat loads as a result of changes in the astronaut's level of activity, open visor operation, solar heat on the spacecraft, and internal spacecraft equipment heating will be experienced and will be reflected in the coolant requirements for the suit heat exchanger. These heat-load changes are not radical under normal conditions and the corresponding coolant flow changes would be small compared with the capacity of the CCV. It is quite possible that the sensitivity of this small-orifice valve, together with the astronaut's normally varying metabolic heat loads, could have resulted in the need for frequent coolant-flow adjustment.

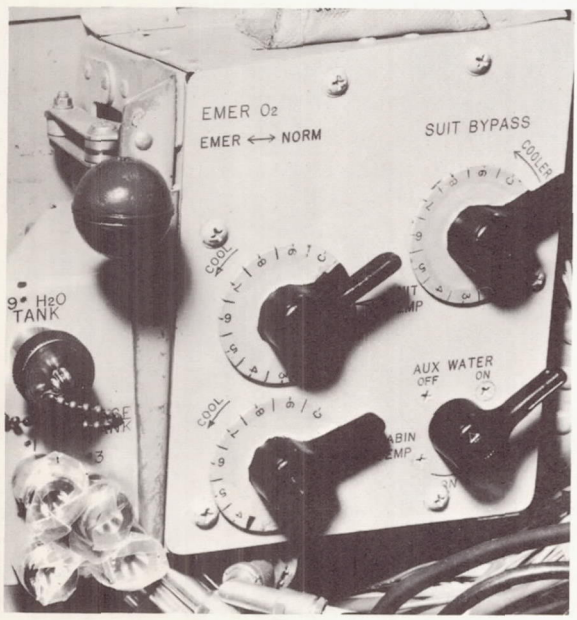



FIGURE 3–17.—Redundant coolant control valve for MA–9.

An inline condensate trap, shown in figure 3–16, was designed to remove excess water from the suit-inlet hose and was installed near the entrance point on the suit. The condensate trap was activated periodically according to the flight plan by the astronaut's opening a hose clamp on the water outlet line from the trap. Condensate water was observed by the astronaut to have been flowing through this line, indicating that free water had probably passed around the sponge.

During the 21st orbital pass, the carbon dioxide ($CO_2$) level at the LiOH canister outlet began to show an increase on the $CO_2$ meter. Postflight chemical analysis of the canister showed definite channeling of the flow through the canister. Channeling is the localized or restricted passage of gas through the canister, rather than a uniform flow for maximum $CO_2$ adsorption. This channeling, which could reduce the effective canister lifetime, has never been experienced during ground testing or during any previous Mercury flight. Based on the amount of unused LiOH at the end of the flight, approximately 27 hours of normal usage remained. However, the actual operating capability of the canister could not be established because of the channeling effects. The exact reason for its occurring on MA–9 could not be established.

The cabin coolant water and fan were turned off according to the flight plan during much of the MA–9 mission in order to evaluate the effectiveness of the cabin cooling circuit. During

this time, the electrical load varied according to mission requirements, and the cabin temperature was observed to cycle between 85° F and 95° F, as indicated in figure 3–18. Reduction in the electrical load during this no-cooling period resulted in corresponding reduction in cabin temperature. It is concluded that cabin cooling was not required during periods in which the Mercury spacecraft electrical system was powered down.

Problems were encountered during MA–9 with the condensate transfer system. The needle of the hand-operated pump, used to transfer liquid from the condensate tank to another container, became clogged with metal shavings from the pump shaft and the condensate could not be transferred. Normally, free water removed by the condensate trap and sponge separator flowed directly to the condensate tank, from which it was then intended to be pumped to storage bags. The condensate tank contained a porous plus to relieve the gas pumped from the sponge into the tank by the action of the sponge separator. Since it was known that this plug could pass water when the tank became nearly filled, the astronaut elected to discontinue operation of the condensate trap when the transfer pump became clogged. This action was taken to stop further flow from the trap to the tank and thereby help to preclude water from being released into the cabin.

No malfunction of the life-support system which compromised the mission or presented a marginal condition to the man occurred during any of the manned Mercury missions. Although minor malfunctions of equipment occurred on these flights, some of which were alleviated by the astronaut, none of these were repeated on successive flights. The suit cooling system has exhibited a history of undesirable operation, characterized by elevated suit inlet temperatures, wet undergarments, and a general lack of astronaut comfort. However, metabolic heat loads were removed sufficiently to keep body temperatures well below a physiologically marginal value. The causes of these cooling system problems for the suit circuit were twofold:

(1) Selection of an improper cooling system control parameter during the initial design period.

(2) Ineffectiveness of the suit-cooling-circuit water separator because of the unpredicted behavior of free liquid in a weightless condition.

Ground testing showed that the steam exhaust duct temperature used in MA–6 and MA–7 missions was not an adequate control parameter for controlling the operation of the heat exchanger. A probe, which sensed the steam temperature at the heat-exchanger dome (see fig. 3–19) between the two coolant evaporating passes, provided a more rapidly responding indication of the heat-exchanger operation. This control temperature parameter was used during the MA–8 and MA–9 flights with satisfactory results. The suit-inlet temperature range of 60° F to 70° F during most of these two flights was more comfortable than the 75° F to 80° F range experienced during MA–6 and MA–7. See figure 3–20 for a summary of suit-inlet temperatures experienced during the four manned orbital flights.

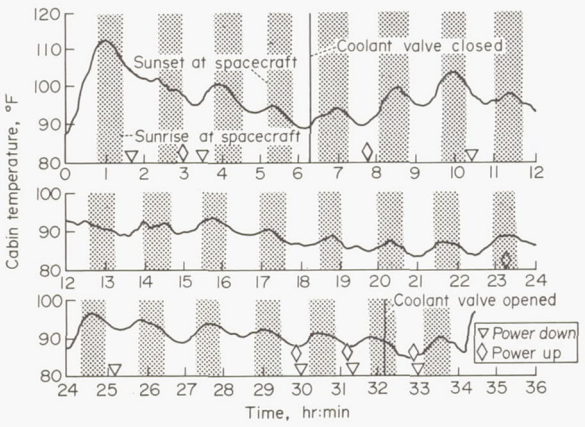



FIGURE 3–18.—Time history of MA–9 spacecraft cabin temperature.

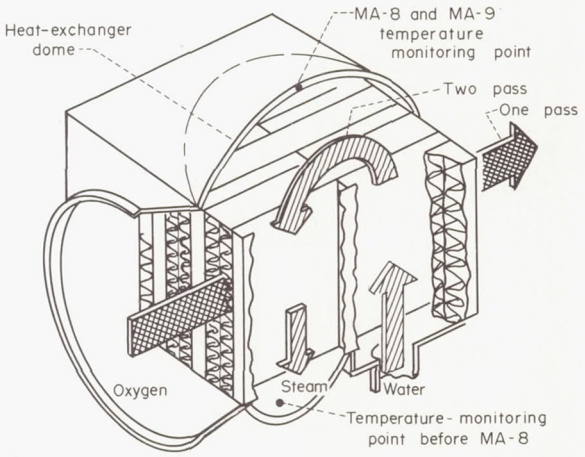



FIGURE 3–19.—Temperature monitoring points on heat exchangers.

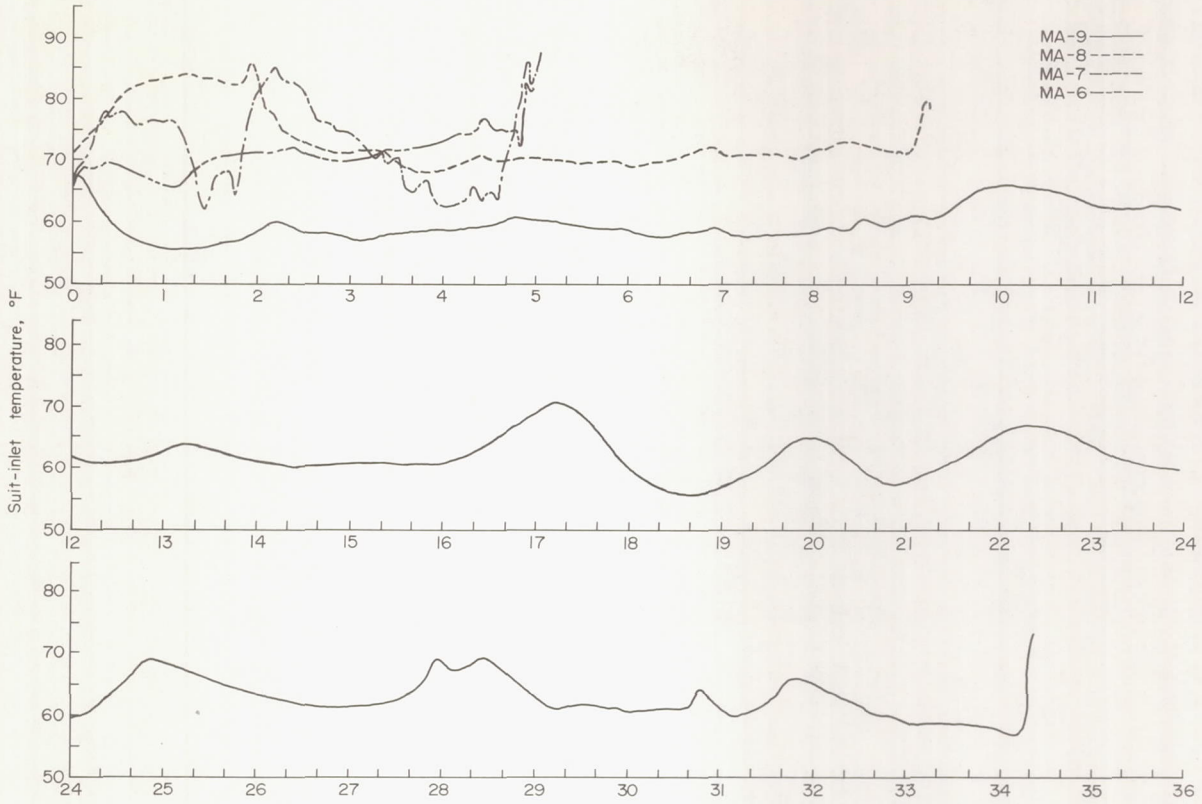



FIGURE 3–20.—Time history for suit-inlet temperature for manned orbital flights.

Other ground tests showed that water in the suit circuit, when condensed from the gas stream in the heat exchanger, was not carried by the gas flow to the sponge separator. This water is believed to have been held under weightlessness to the metal surfaces by surface tension and flowed from the cooling surfaces to the duct walls, thereby probably passing around the sponge in the separator. The condensate trap, which was installed in the MA–9 ECS, verified the need for a trap which will remove free condensate water traveling along the duct walls. Missions of even longer durations will require the extraction of all free condensate to keep the astronaut's body dry and thereby to obtain maximum comfort and hygiene.

#### Electrical and Sequential Systems

Except for some early development problems in the sequential system, this system group has performed satisfactorily throughout the Mercury program. Although there were no serious sequential problems throughout the manned flight program, there was an early deployment of the main parachute during the MR–4 mission and of the drogue parachute during MA–6. The reasons for these premature deployments have never been fully understood, since no system malfunction could be found during exhaustive postflight testing. During the later manned orbital missions, a modification to the sensing circuits for these sequential functions guarded against premature automatic deployment. The contractor was instructed to conduct a single-point failure analysis, which involved a detailed study of the electrical and sequential circuitry to establish all possible failure modes, and this analysis was conducted for all spacecraft systems before the MA–7 flight. The results of this study were evaluated for failure conditions that would singularly jeopardize flight safety, and appropriate modifications were incorporated into the MA–7 and subsequent spacecraft to improve reliability. The greater portion of these changes involved the electrical and sequential systems because of their unique relationship to critical mission functions. These changes dictated paralleling of redundant sensing ele-

ments in some cases in which the actuation of either element could initiate the proper function. In other cases where it was important that an event signal not be sent early, some elements were changed to a series function, as was done for the parachute-deployment circuitry.

The primary change to the electrical system for the MA–9 mission was the replacement of two 1,500-watt-hour batteries with two 3,000-watt-hour batteries. This change brought the power supply up to one 1,500-watt-hour and five 3,000-watt-hour batteries.

During the early phases of the flight program, difficulty was experienced in maintaining the temperatures of the electrical inverters below the maximum recommended operating level. A cooling system was subsequently installed for the two main inverters, but contamination problems and the limited effectiveness of this cooling system did not alleviate the elevated temperature situation appreciably. However, continued operation of these inverters from mission to mission, in conjunction with ground test results, without experiencing a temperature-associated failure, provided sufficient confidence that these units would operate satisfactorily. Finally, for the MA–9 mission, modified inverters with improved thermal characteristics were installed in place of two of the old style units (main 250 v-amp and 150 v-amp) and the open-cycle evaporative cooling system was deleted. The three spacecraft inverters functioned satisfactorily until late in the MA–9 flight when an electrical short circuit prevented their operating properly.

In the MA–9 flight, the failure which caused the greatest concern was first recognized at the early illumination of the 0.05g sequence light, which indicated that the automatic stabilization and control system (ASCS) had possibly switched to its reentry mode of operation, which would have included the initiation of rate damping and a steady spacecraft roll rate. Subsequent checks by the astronaut revealed, in fact, that this control mode had been enabled. A requirement for a manual retrofire maneuver was therefore imposed on the astronaut, but it was still the plan to use the autopilot during reentry. However, soon after this occurrence, the main inverter ceased to supply a-c power, and, in the switchover to the standby unit, this redundant element did not start properly. (Refer to fig. 3–21 for details involving the ASCS and power supplies.) Without a-c power for the control system, even the reentry control configuration was disabled; therefore, the astronaut was required to conduct this maneuver with manual control. This task was further complicated by a corresponding loss of gyro attitude indications because of the a-c power failure. A postflight inspection and analysis

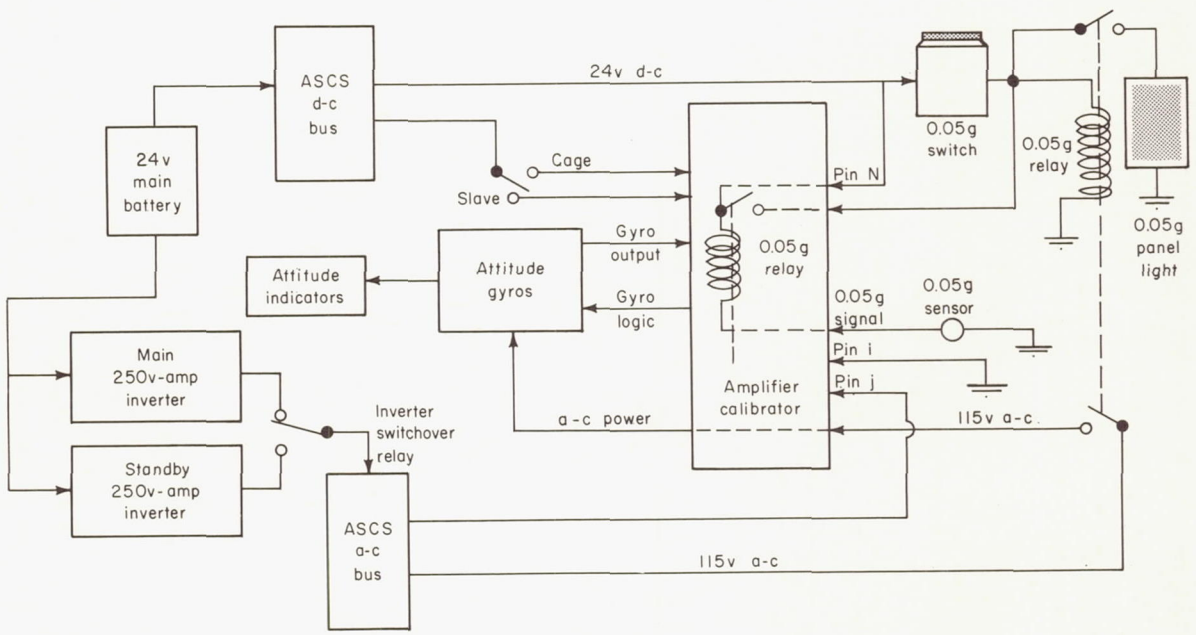


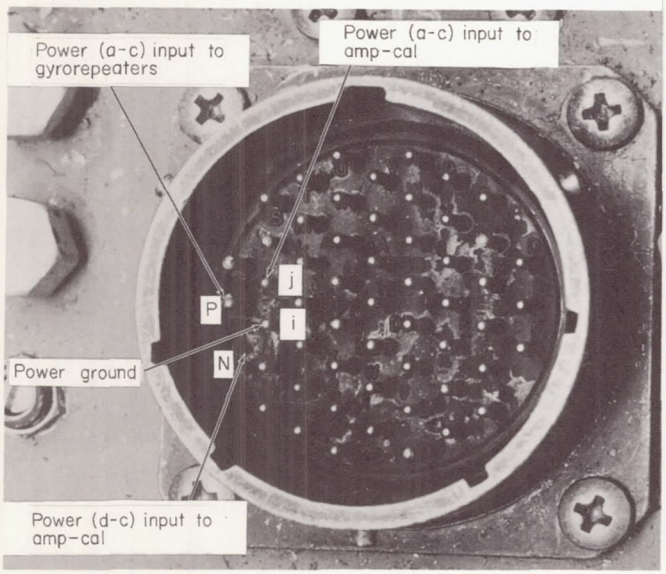

FIGURE 3–21.—Relationship of electrical power to control system autopilot.

of the trouble areas disclosed that a short circuit had occurred, both on the power plug (shown in fig. 3–22) to the ASCS amplifier-calibrator and to another connector (see fig. 3–23), also part of the ASCS power circuit. Both inverters under question were tested thoroughly after the flight and found to operate within specification, indicating that they did not contribute to the malfunction. Strong evidence exists that free water in the spacecraft cabin had been present near the multipin power-plug connection and eventually provided a current path in the insulation between the d-c power and grounding pins shown in right-hand photograph in figure 3–22. Pin N, labeled in the figure, was found to have been completely burned off. Figure 3–23 clearly indicates the significant corrosion revealed on the second connector during the post-flight disassembly and inspection.

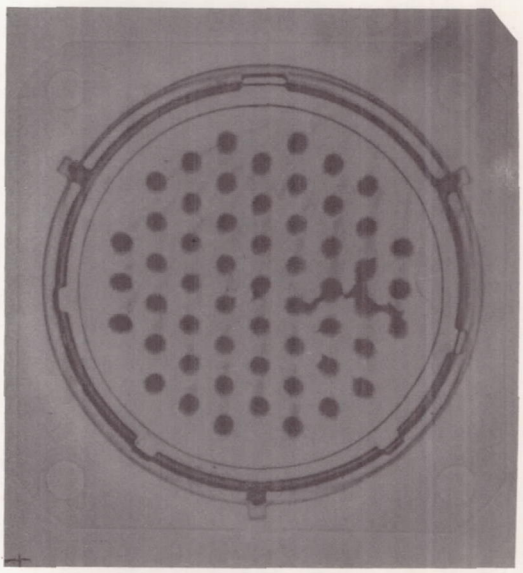
Postflight tests duplicated the above hypothesis; that is, a short to ground could be effected upon application of condensate water. Resistance measurements taken across certain pins of the second plug immediately following the flight indicated electrical paths that could have caused the 0.05g indication. A likely source of the liquid which might have caused the electrical short circuit was the porous vent of the condensate tank in the environmental control system. This tank is located in the proximity of the auto-pilot power plugs, and normal cycling of the sponge squeezer during the flight could have forced condensate through the vent. Another possible source of water which could have produced the short circuit is the local condensation of cabin humidity, which may have been present because of a leak in the drinking-water valve or because of water vapor exhaled by the pilot when his helmet faceplate was open. Or the water droplets which leaked from the valve may have somehow been deposited, in part, directly on the power plug. This experience points up the need to minimize or eliminate the presence of free liquid or high humidity in a spacecraft cabin where electrical systems are functioning and to insulate and seal bare electrical connectors more effectively.



FIGURE 3–23.—Postflight photograph of MA–9 connector-socket rear face.




(a)—Front view showing burnt pin.



(b)—Rear view showing X-rayed current paths in insulation.

FIGURE 3–22.—Postflight photograph of MA–9 auto-pilot power plug.

## Concluding Remarks

The Mercury spacecraft systems design and development phases were conducted concurrently and although this philosophy involved a known risk, it made possible the early realization of the project objectives. During this time, many valuable lessons were learned and exploited in the development and operation of manned space-flight systems.

In the system design, maximum use was made of existing technology and off-the-shelf equipment, and systems concepts were kept simple. However, some important advances in the technology also had to be initiated. It was found that the spacecraft and its systems must be designed for operational conditions. Examples of the design-for-operation standard relating to the preflight activities are system accessibility and the simplification of system interfaces. It is also important in the early system design to allow for an inevitable growth in weight.

During development and qualification testing, the test criteria cannot be compromised in most instances, since an overlooked system inefficiency will inevitably show up later where a redesign is more costly. However, it was also found in Mercury that no single qualification criterion necessarily applies to all systems, and local operational conditions must be individually evaluated for each system. Whenever system components are significantly modified, as was done for the *Faith 7* spacecraft to make possible the 34-hour flight capability, a new ground test program for hardware requalification should be administered to insure maintenance of previous reliability and operational standards.

In the area of hardware operation and performance evaluation, the Mercury flight program has been a most valuable experience. The most important lesson learned from operation of the spacecraft control system is that the pilot is a reliable backup to automatic system modes. In fact, the pilot's ability to control accurately the spacecraft attitude was instrumental in three of the four manned orbital flights in completing the mission successfully when a malfunction was present in the automatic system. Another valuable lesson in both the control system and cooling system designs was the avoidance of components which are especially sensitive to contamination. The small valves used to meter reaction control fuel and environmental control system cooling water should have been designed to employ larger flow areas to reduce susceptibility to particle blockage. Other than guarding against stray voltages and sensitivity to transients, the major lesson derived from the performance of the electrical and sequential systems was the need to seal and insulate effectively all electrical connectors from possible sources of free liquid and humidity in the spacecraft cabin. In the life support system, it was also found that the cooling systems must be designed with adequate margins and that food, water, and waste management devices require particular attention because of plumbing complexity and the effects of weightlessness.

Throughout the Mercury development and flight programs, quality control and rigid manufacturing standards were found to be absolutely mandatory if incidental flight failures and discrepancies were to be avoided. Throughout the project, a careful and continuing attention was given to engineering detail in order to make possible the early recognition of system weaknesses and their implications in the operation of flight hardware and to provide meaningful and effective courses of action. This attention to detail was an important reason for the success of the Mercury flight program, particularly the manned suborbital and orbital missions.

*Acknowledgement.*—The authors wish to gratefully acknowledge the analytical and documentary efforts of the many NASA engineers and technicians who applied their knowledge and foresight unselfishly during the postflight evaluations of the various spacecraft systems for each Mercury mission and without whose contributions this paper would not have been possible.

## References


1. Faget, M. A., and Piland, R. O.: *Mercury Capsule and its Flight Systems.* IAS Paper No. 60–34, Presented at IAS 28th Annual Meeting (New York, N.Y.), Jan. 25–27, 1960.
2. Anderton, David A.: *How Mercury Capsule Design Evolved.* Aviation Week, Vol. 74, No. 21, May 22, 1961.
3. Bond, Aleck C.: *Mercury Spacecraft Systems.* Proc. Conf. on Results of the First U.S. Manned Suborbital Space Flight. NASA, Nat. Inst. Health, Nat. Acad. Sci., June 6, 1961, pp. 11–18.
4. Hammack, Jerome B.: *Spacecraft and Flight Plan for Mercury–Redstone 4 Flight.* Results of the Second U.S. Manned Suborbital Space Flight, July 21, 1961. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 3–8.
5. Kleinknecht, Kenneth S., Bland, William M., Jr., and Fields, E. M.: *Spacecraft and Spacecraft Systems.* Results of the First U.S. Manned Orbital Space Flight, February 20, 1962. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 5–30.
6. Johnston, Richard S., Samonski, Frank H., Jr., Lippitt, Maxwell W., and Radnofsky, Matthew I.: *Life Support Systems and Biomedical Instrumentation.* Results of the First U.S. Mannned Orbital Space Flight, February 20, 1962. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 31–44.
7. Voas, Robert B.: *Manual Control of the Mercury Spacecraft.* Astronautics, Vol. 7, No. 3, March 1962, pp. 18–20 and 34–38.
8. Boynton, John H., and Fields, E. M.: *Spacecraft and Launch-Vehicle Performance.* Results of the Second United States Manned Orbital Space Flight, May 24, 1962. NASA SP–6, Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 1–14.
9. Anon: *Mercury Provides Data for Apollo, Gemini.* Aviation Week, Vol. 77, No. 1, July 2, 1962, pp. 98–99.
10. Boynton, John H., and Fisher, Lewis R.: *Spacecraft and Launch-Vehicle Performance.* Results of the Third United States Manned Orbital Space Flight, October 3, 1962. NASA SP–12, Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 1–11.
11. Bland, William M., Jr., and Berry, Charles A.: *Project Mercury Experiences.* Astronautics and Aerospace Engineering, Vol. 1, No. 1, Feb. 1963, pp. 29–34.

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# 4. MERCURY-REDSTONE LAUNCH-VEHICLE DEVELOPMENT AND PERFORMANCE

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**Summary**

The Mercury-Redstone launch vehicle was used for the first United States ballistic manned space flights. As a prelude to the orbital flight program, the Mercury-Redstone missions provided an opportunity to evaluate the performance of the Mercury spacecraft, the reactions of the astronauts to brief periods of space flight, and the launch and recovery operations. The first steps toward man-rating a tactical missile were made in a series of design changes and modifications based on ground and flight testing. This paper describes development of the first U.S. manned launch vehicle, including the abort system, the reliability programs necessary for pilot safety, and the performance of the Mercury-Redstone space vehicle.

## Introduction

The Mercury-Redstone launch vehicle was the United States' first manned launch vehicle. However, it is only the first of a series of launch vehicles which will exhibit an increasing capability in manned space payloads.

By early 1959, several decisions were made in regard to the performance required of a launch vehicle needed for the first phase of the manned flight program. The vehicle had to have both the reliability and performance to place a manned, 2-ton payload safely into a suborbital trajectory in which at least 5 minutes of weightlessness would be experienced and an apogee of at least 100 nautical miles would be attained. In addition, the vehicle had to be available in time to support the desired flight schedule. These requirements narrowed the choice to launch vehicles which had already been developed for a military mission.

At this time, two surplus Jupiter C missiles were available from the Army Ballistic Missile Agency (ABMA). The Jupiter C was an advanced version of the Redstone, a tactical military missile with a record of over 50 successful flights to verify its reliability. The original Redstone could not meet the mission requirements; however, the Jupiter C had elongated propellant tanks, a lighter structure, and the required performance for Mercury. The Jupiter C launch vehicle had been used for conducting reentry studies and placing the first U.S. satellite, *Explorer I*, into orbit.

Therefore, the Redstone vehicle, in its Jupiter C modification, satisfied the basic Mercury suborbital requirements of availability and performance.

However, the Jupiter C did not incorporate all the necessary safety features; and further adaptation was necessary for use as a manned launch vehicle. This development, which is sometimes referred to as "man rating," had as its three major guidelines safety during launch, satisfactory operation from a human-factors standpoint, and adequate performance margins.

The actual adaptation took place in three phases: basic modifications, modifications after ground tests, and modifications after flight tests. Although there were specific hardware changes during the development, the basic man-rating program and design concepts did not require major alteration.

## Basic Vehicle Modification

As noted, some basic modification was necessary to adapt the Jupiter C to the Mercury mission requirements. The required modifications

and additions made the new Mercury-Redstone launch vehicle physically distinguishable from both the Redstone and Jupiter C missiles. Figure 4–1 illustrates the differences between these configurations. It should be noted that each successive version of the original Redstone was progressively longer.

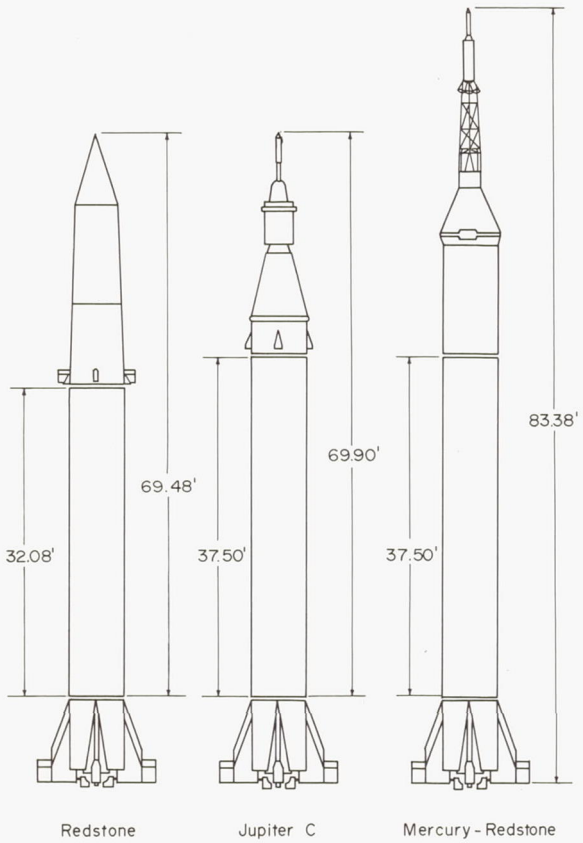



FIGURE 4–1.—Comparison of the three Redstone missiles.

To meet performance requirements, use of the elongated Jupiter C tanks was necessary. These tanks give the Mercury-Redstone launch vehicle a nominal engine burning time of 143.5 seconds, 20 seconds more than the original Redstone vehicle. This greater burning time required the addition of a seventh high-pressure nitrogen tank to pressurize the larger fuel tank and an auxiliary hydrogen peroxide ($H_2O_2$) tank to power the engine turbopump.

To decrease the complexity for the basic Mercury-Redstone, three changes were made:

(1) The Redstone stabilized platform (ST–80) were replaced by the LEV–3 autopilot for vehicle guidance. The LEV–3 system, although less complex, was more reliable and met the guidance requirements of the Mercury-Redstone mission.

(2) The aft unit, containing the pressurized instrument compartment, and adapter were permanently attached to the center tank assembly. In the tactical version, these units separated with the payload to provide terminal guidance.

(3) A short spacecraft adapter, including the spacecraft-launch-vehicle separation plane, was supplied by the spacecraft contractor. This arrangement simplified the interface coordination.

To prevent major changes midway in the program, the engine was immediately changed from the A–6 to the A–7 model. The A–6 engine was scheduled to be phased out, and a shortage of hardware was expected to occur during the Mercury-Redstone program. This early changeover avoided a foreseeable problem area but required an accelerated test program.

For the Mercury-Redstone launch vehicle, alcohol was chosen as the fuel. Although the Jupiter C had used unsymmetrical diethyltriamine (UDETA) for greater performance, its toxicity was higher than that of alcohol and was considered to be undesirable for manned flights. However, the selection of alcohol led to a problem with the important jet control vanes because of the extended burning time which caused greater erosion of these vanes. Hence, a program was initiated to select jet vanes of the highest quality for use in Mercury.

The prevalves were deleted from the Mercury-Redstone launch vehicle in order to increase mission success. These valves had been used in the tactical missiles between the propellant tanks and the main propellant valves to prevent possible fuel spillage in the event of a main valve failure. However, failure of the prevalves to remain open in flight would have resulted in a mission abort.

To provide for maximum crew safety, an automatic inflight abort-sensing system was added to the launch vehicle and an emergency egress operation was established for the launch complex. These factors were primary considerations in man-rating the Redstone and are discussed in greater detail later.

The Mercury-Redstone was aerodynamically less stable than the standard Redstone. Because of the unique payload characteristics and

the elongated tanks, the Mercury-Redstone was expected to become unstable in the supersonic region approximately 88 seconds after lift-off. (See fig. 4–2.) To compensate for this instability to some degree, 687 pounds of ballast were added forward of the instrument compartment.

Changes were also necessary because of the decreased lateral bending frequencies. The configuration and payload changes reduced the Mercury-Redstone bending frequencies to one-fourth those experienced by the standard Redstone. (See fig. 4–3.) As a result, resonance problems appeared during both ground and flight testing. The second bending mode had to be filtered out of the control system to prevent feedback.

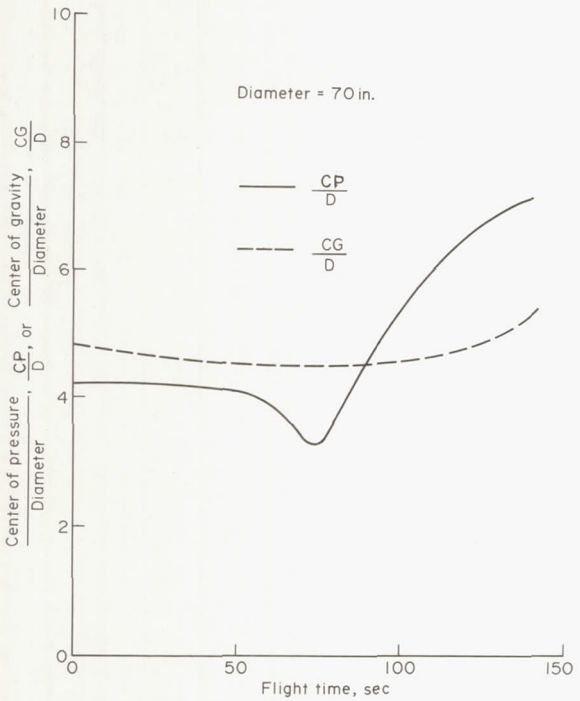



FIGURE 4–2.—Center-of-gravity and center-of-pressure location of Mercury-Redstone during time of flight.

In all, a total of 800 changes were made before the Mercury-Redstone project was completed. The major modifications just described, as well as many minor changes beyond the scope of this paper, resulted in a reliable man-rated vehicle.

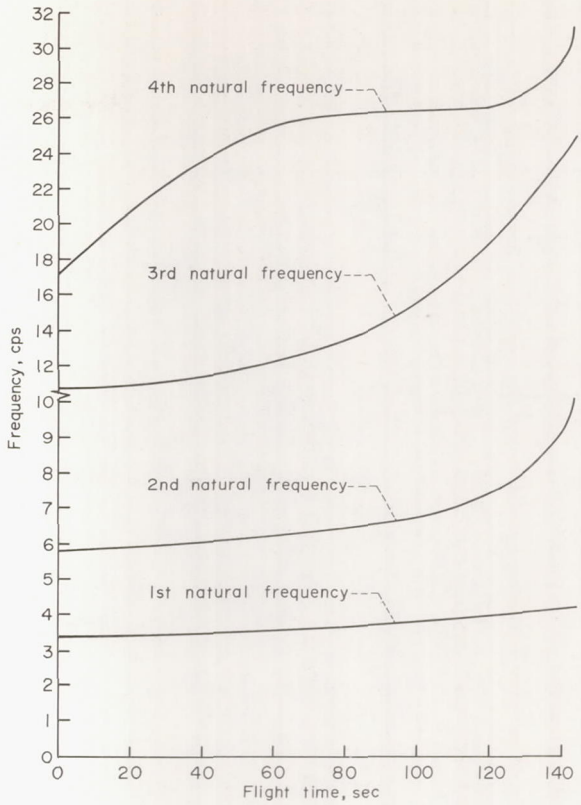



FIGURE 4–3.—Mercury-Redstone lateral bending modes.

## Abort System Description

Even though the vehicle was expected to perform properly, a launch-escape system was required for maximum crew safety as long as a catastrophic launch-vehicle failure remained a possibility. Therefore, an automatic inflight system was developed which supplied an abort signal to the spacecraft in the event of an impending catastrophic failure of the launch vehicle. This signal caused engine cut-off, escape-rocket ignition, and spacecraft separation. This cut-off mode was in addition to those sent when the mission conditions were achieved and in the event an emergency command destruct signal had to be sent. Because the vehicle was to be manned, the destruct signal had a built in 3-second delay to allow time for adequate spacecraft separation. The abort system, shown in figure 4–4, sensed and was activated by: unacceptable deviations in the programed attitude of the launch vehicle, excessive turning rates, loss of thrust or loss of electrical power.

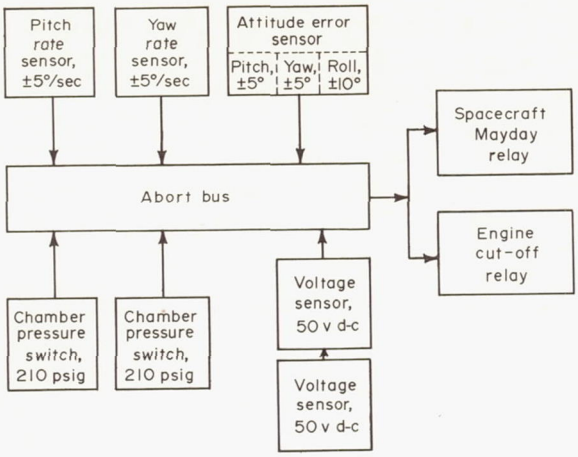



FIGURE 4–4.—Block diagram of Mercury-Redstone automatic abort sensing system.

The criteria for the abort system were based on an evaluation of over 60 Redstone and Jupiter C flights and a failure-mode analysis. The number of parameters was kept at a minimum, since an overly complicated system could result in little improvement, if any, in overall flight safety. A selection of those parameters which would reflect the operation of only vital systems was therefore required. Hence the abort system sensed primarily output or downstream parameters, each of which were then representative of many different types of failures.

For example, a sudden change in the attitude of the vehicle indicated trouble in the control system, regardless of the source of this trouble. It could be the result of a failure in the control computer or some mechanical system or the limits of controllability having been exceeded. By establishing critical values for pitch, yaw, and roll angle, a variety of problems, including the unstable "flip-over" with a subsequent explosion, could be predicted in time for a safe abort. As other examples, loss of thrust, rough combustion, and an impending explosion could be sensed from variations in the combustion chamber pressure. Finally, a loss in electrical power or of the electrical interface between the spacecraft and launch vehicle could be effectively sensed.

As shown in figure 4–4, the abort system circuitry was designed to include adequate redundancy. The combustion chamber pressure ($P_c$) switches were wired in parallel to assure an abort capability even if one sensor failed. Since the predominant failure mode of electrical voltage sensors is opposite that for a pressure switch, the relays controlled by the voltage sensors were connected in series. Although a single sensor monitored pitch, yaw, and roll attitudes, as well as pitch and yaw attitude rates, redundancy was implicit for these attitude and rate measurements because of their interdependency.

To supply the necessary timing functions to the abort system, relay interlocks were used to prevent arming of the abort system prior to lift-off and to disarm the system at normal shutdown. The $P_c$ switches were armed after engine start and disabled prior to normal shutdown. Here, additional relays also provided circuit redundancy and lock-in of the abort signal.

Time is a critical factor in the abort procedures, and the method of abort initiation is completely dependent on it. Because some launch vehicle failures could very rapidly result in a catastrophe, the abort was designed to be automatically initiated. Since some failures would not cause an immediate catastrophe, manual backup was incorporated. The astronaut, blockhouse, mission control center, and range safety could initiate an abort during specifically assigned flight periods, some of which overlapped.

### Nominal Mission Profiles

The Mercury-Redstone launch vehicle, whose nominal mission profile is shown in figure 4–5, accelerated the Mercury spacecraft into a suborbital flight at a nominal speed of approximately 6,460 feet per second. At launch-vehicle–spacecraft separation the flight-path angle was 41.80°, the altitude, 200,000 feet, and the Mach number, 6.30. The maximum acceleration at cut-off was 6.3g.

In figure 4–5, several important launch vehicle sequencing points are indicated. A circuit permitting automatic engine cut-off prior to abort was activated 30 seconds after lift-off. Prior to this time, this circuit was disabled because cut-off in the first 30 seconds would have resulted in an impact of the launch vehicle on land which was undesirable; therefore, only the range safety officer could initiate an engine shutdown. To prevent an early jettisoning of the

escape tower the normal shutdown circuitry was not armed until 129.5 seconds. At 131 seconds the velocity cut-off accelerometer was armed. This arming occurred 12 seconds before nominal expected engine cut-off time to allow for higher-than-expected launch-vehicle performance for a non-optimum mixture ratio, which could result in premature propellant depletion. The chamber pressure sensors to the automatic abort system were deactivated at 135 seconds, thus preventing an abort signal at the time of cut-off. Both cut-off activation and pressure switch deactivation were originally scheduled to occur at 137.5 seconds, but as a result of the early shutdown of MR–2, the times indicated in the figure were selected for all subsequent flights.

At engine shutdown, nominally at 143 seconds, the abort system was deactivated and the escape tower jettisoned. Spacecraft separation occurred 9.5 seconds after shutdown to allow for thrust tail-off.

## Reliability, Testing, and Quality Assurance

As mentioned earlier, the basic launch vehicle had a history of 69 flights prior to the first manned flight upon which to base failure-mode and reliability prediction. Two such predictions were made. The first prediction used the record of all Redstone, Jupiter C, and Mercury–Redstone development and qualification flights. The second prediction used an artificial Redstone configuration composed of individual components flown at different times on previous flights.

To find the weak spots in the total vehicle, large subsystems were submitted to a special reliability test program. All major missile sections and the systems contained in each were vibrated under temperature and humidity conditions simulating the actual environments of transportation, prelaunch, and flight. Bending and compression loads were applied up to 150

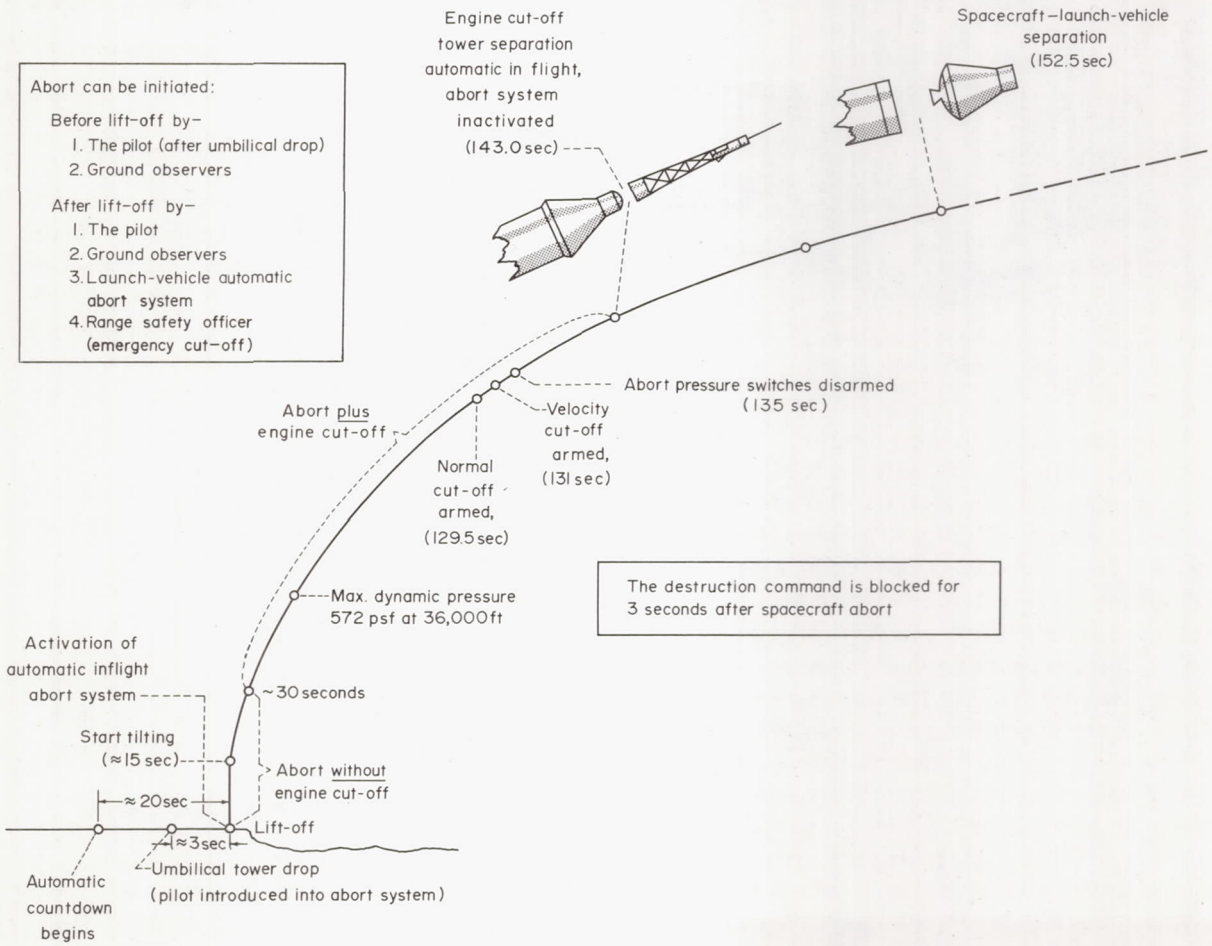



FIGURE 4–5.—Mercury-Redstone powered flight sequence.

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percent of maximum flight loads, thereby establishing positive margins of safety. When trouble spots were found, individual component testing was followed up with additional systems tests.

Figure 4–6 shows the vehicle contractor's combined environmental test facility. This facility applied flight vibrations and rigid body motions up to 4g at 2,000 cps simultaneously with temperatures up to 115° F. This testing proved the importance of investigating the interaction of all component masses.

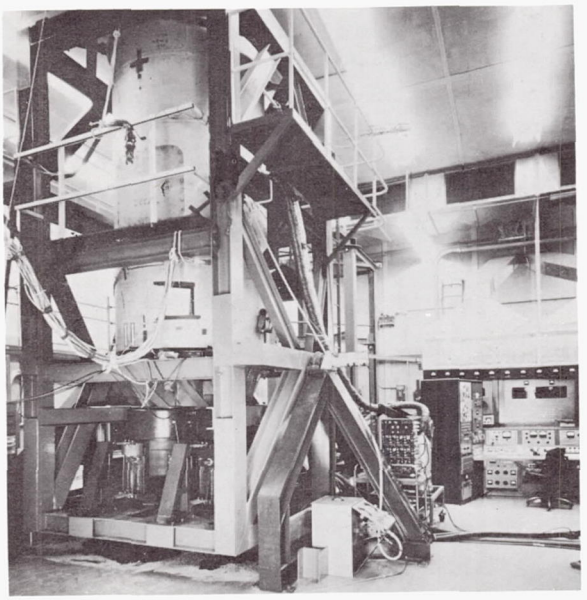


FIGURE 4–6.—The contractor's combined vehicle motion and vibration test stand.

In addition, structural flight simulation, spacecraft–launch-vehicle interface compatibility, clamp-ring operation, and static firing tests were made. Figure 4–7 shows the mating of the spacecraft and launch vehicle prior to a noise and vibration test conducted at the NASA Marshall Space Flight Center (MSFC).

Quality assurance procedures were relatively more refined than for the tactical vehicle because of the stress placed on crew safety. An awareness program required that every Mercury system assembly carry a special Mercury stamp indicating that it had passed special inspections and that all personnel involved in its manufacture and assembly were aware of the quality expected. Particular attention was paid the areas involving soldering techniques, welding repairs, and preparation of instructions.

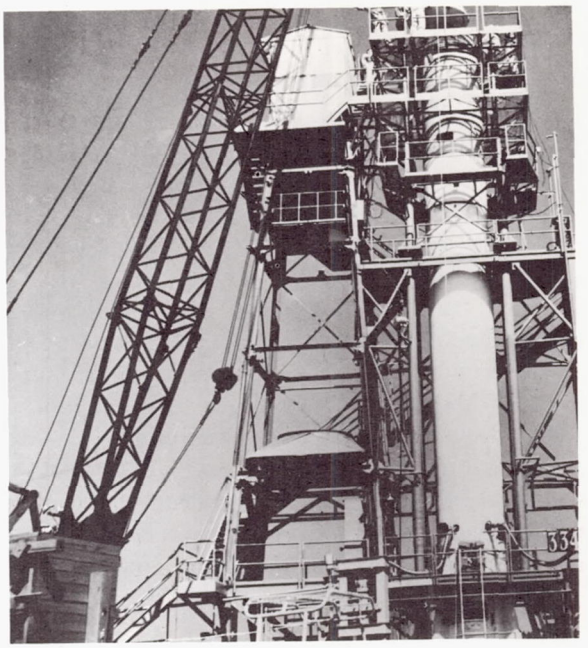


FIGURE 4–7.—Static firing, noise and vibration test stand.

### Changes Resulting From Ground Tests

During the vibration test program, several components failed or were damaged. These components included an engine piping elbow, an $H_2O_2$ bottle bracket, the abort-rate switch-mounting bracket, wires in the roll-rate switch, and an antenna mounting stud. Similar problems occurred in other components. The success of the modifications proved the value of total system testing.

Since the A–7 engine was new, extensive test firings were made. During these firings, an instability was discovered at 500 cps and eliminated through a modification to the fuel injector. Investigation as to the source of another low-frequency oscillation eventually led to the discovery that the static test tower was at fault. Modification of the static test tower subsequently removed it as a trouble source.

### Checkout and Launch Operations

Prior to shipment to the launch site at Cape Canaveral, the Mercury-Redstone abort system was checked by introducing simulated malfunctions and evaluating the abort system responses.

The first three launch vehicles were also carefully tested for compatibility with the spacecraft at MSFC.

At Cape Canaveral, the Mercury-Redstone countdown was conducted in two parts with a rest period in between to reduce fatigue of the launch crew. Lox loading was scheduled for completion at 180 minutes prior to lift-off to minimize the possibility of an additional 12-hour delay for lox tank purging and drying during the recycle time in the event of a launch cancellation after lox loading. The astronaut was to be inserted into the spacecraft after lox loading at approximately 120 minutes prior to lift-off. A period of 4 hours was considered to be a tolerable time between astronaut insertion and lift-off to accommodate possible holds in the countdown.

### Emergency Egress and Pad Abort

Special astronaut safety precautions were required after insertion since the launch vehicle was already fueled; therefore, launch pad emergency egress procedures were developed. A study (see fig. 4–8) to determine the best mode to retrieve an incapacitated astronaut indicated the blockhouse-controlled service structure would provide the most expeditious escape. If, however, he were able to exit without help,

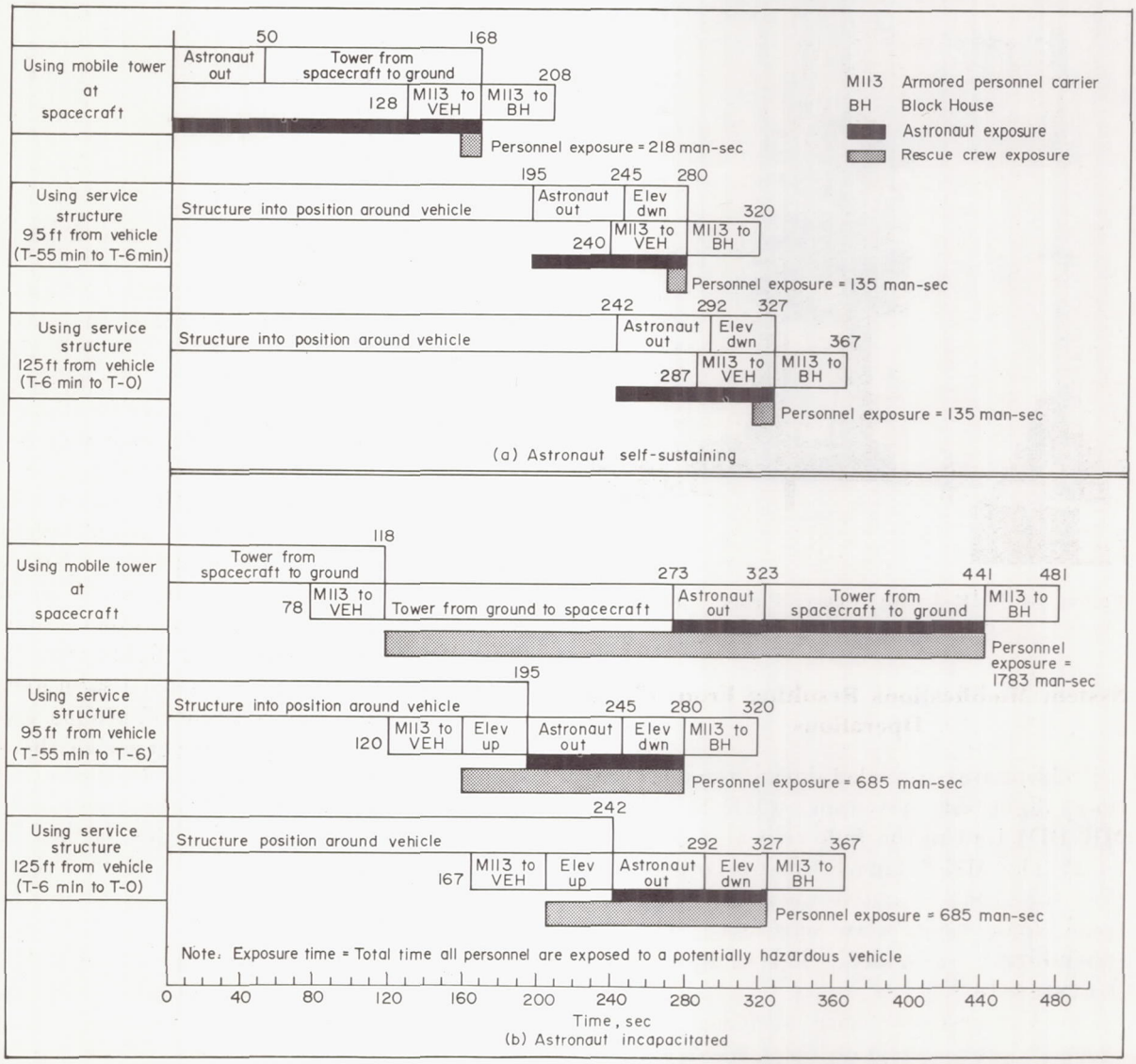



FIGURE 4–8.—Time study of astronaut emergency egress.

he could use the pad escape tower, or "Cherry Picker," shown in figure 4–9. The cab of this specialized escape equipment, which was permanent but extendable, was stationed near the spacecraft hatch until just prior to lift-off. Utilization of this escape device was combined with the use of fire trucks, an armored personnel carrier (M–113), and rescue teams for exit from the pad area. In case of a pad abort, recovery procedures and vehicles, including army helicopters and amphibious craft, were organized and prepared to assist.

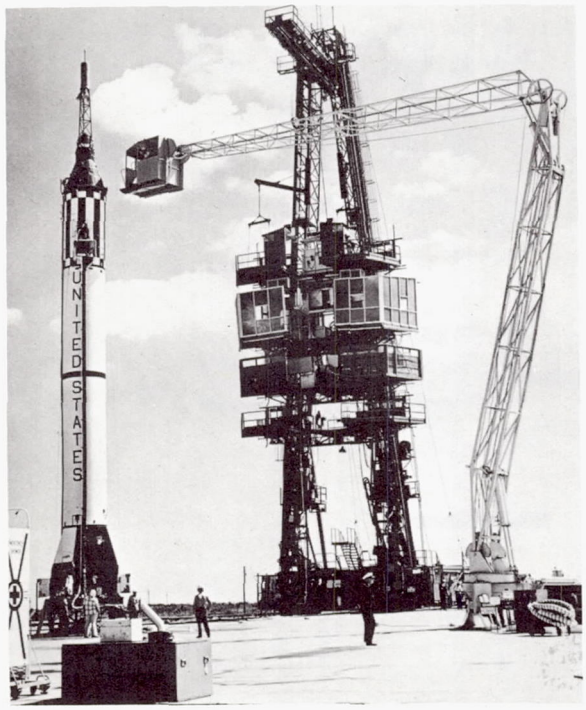



FIGURE 4–9.—MR–3 with "Cherry Picker" and remote controlled service structure.

## System Modifications Resulting From Flight Operations

Problem areas revealed during the qualification flight-test program (MR–1, MR–2, MR–BD) lead to the following modifications:

(1) The MR–1 launch attempt proved the need for ground-negative until all other electrical connections were separated. Thus, a ground strap was added. This strap is shown in figure 4–10.

(2) A scale-factor error resulting from an excessive pivot torque on the LEV–3 longitudinal integrating accelerometer caused the MR–1A launch vehicle to experience a cut-off velocity exceeding the nominal value by about 260 feet per second. Use of softer wire and the relocation of the electrical leads eliminated the problem.

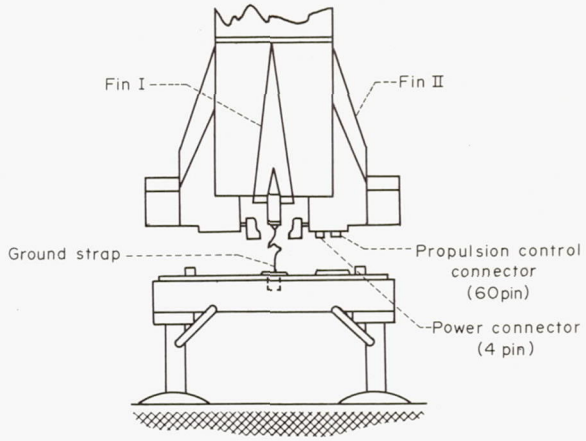



FIGURE 4–10.—Mercury-Redstone ground strap.

(3) As a backup to the integrating accelerometer fix, a time-based cut-off signal was established at 143 sec for the MR–2 and MR–BD (booster development) missions. These later flights proved that the accelerometer functioned properly, and use of the cut-off timer was discontinued.

(4) The thrust controller on MR–2 failed wide open causing lox depletion 0.5 second before deactivation of the abort $P_c$ switches and before integrating accelerometer arming, which could have prevented this trouble. To prevent a similar occurrence on the remaining flights, velocity cut-off arming and $P_c$ abort switch disarm were separated in time. Velocity cut-off arming was advanced to 131 sec to take care of earlier-than-predicted cut-off velocity, while $P_c$ disarming was set at 135 sec, keeping the combustion chamber pressure abort capability as long as possible, but removing this capability early enough to take care of a high propellant consumption rate.

(5) Flights MR–1A, MR–2, and MR–BD experienced momentary roll rates approximately twice that of the earlier Redstone vehicle ($\sim$ 8°/sec as against $\sim$ 4°/sec—abort limits were 12°/sec). Since the missile was not

subject to damage at this rate, the roll-rate abort sensor was deleted after MR–BD to increase mission success. The roll attitude angle abort limit of 10° was retained.

(6) An interaction of the second bending mode with the yaw and pitch axis control required the addition of a network filter to reduce control loop gain between 6 and 10 cps. The interaction was noted on flights MR–1A and MR–2 and is illustrated in figure 4–11.

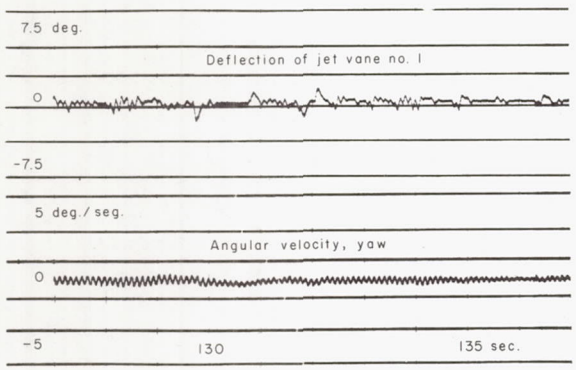



FIGURE 4–11.—Second bending mode oscillations in yaw toward end of MR–1A flight.

(7) During MR–1A, MR–2, and MR–BD, undesirable vibrations in the adapter and instrument compartment were evident. On MR–3 these were dampened with 340 pounds of lead-impregnated plastic compound added to the bulkhead and walls of the section. The weight of this compound was substituted for an equal amount of ballast weight. Fourteen longitudinal stiffeners were also added to the internal skin surface. These improvements are depicted in figure 4–12. Since Astronaut Shepard still noted considerable vibrations during powered flight in MR–3, an additional 102 pounds of the dampening compound, X306, were added to the instrument compartment of MR–4. The summation of these changes resulted in the Mercury-Redstone shown in figure 4–13.

### Flight Results

Three qualification flights were conducted for the Mercury-Redstone flight series. MR–1 was launched on November 21, 1960. After rising a few inches, it settled vertically back on the launcher. It proved the need for careful examination of electrical circuitry and led to the addition of a strap for proper electrical grounding.

The sequence of events which led to MR–1's difficulties started during the lift-off when the power and control connectors did not disconnect simultaneously. Because of mechanical adjustments, the power plug disconnected 29 milliseconds prior to the control plug. This permitted part of a 3-amp current, which would have normally returned to ground through the power plug, to pass through the "normal cut-off" relay and its ground diode. The cut-off terminated thrust and jettisoned the escape tower.

The spacecraft did not separate from the launch vehicle because the g-load sensing requirements in the spacecraft were not met. "Normal cut-off" started a 10-second timer which, upon its expiration, was supposed to signal separation if the spacecraft acceleration was less than 0.25g. (This sequencing was designed to minimize the occurrence of a spacecraft launch-vehicle recontact. However, MR–1 had settled on the pad before the timer expired and the g-switch sensing lg blocked the separation signal.)

The barostats properly sensed that the altitude was less than 10,000 ft and therefore actuated the drogue, main, and reserve parachutes in the proper sequence. The reserve parachute was released because no load was sensed on the main parachute load sensors. To prevent this failure from recurring, engine pressure was monitored and, if normal at 129.5 seconds, the normal booster cut-off signal path to the spacecraft was armed.

Following the MR–1 attempt, the spacecraft was refurbished and mated to a new launch vehicle, scheduled to be launched as MR–1A. The MR–1A space vehicle successfully accomplished the MR–1 mission objectives on December 19, 1960. The launch was slightly compromised by a scale-factor error in the longitudinal integrating accelerometer which caused cut-off velocity to be 260 feet per second higher than normal. This higher velocity caused the spacecraft to experience somewhat higher reentry deceleration. During the flight, all measured abort parameters remained below the limits and the abort system functioned as expected.

MR–2, launched January 31, 1961, carried a chimpanzee named "Ham." On this flight, the

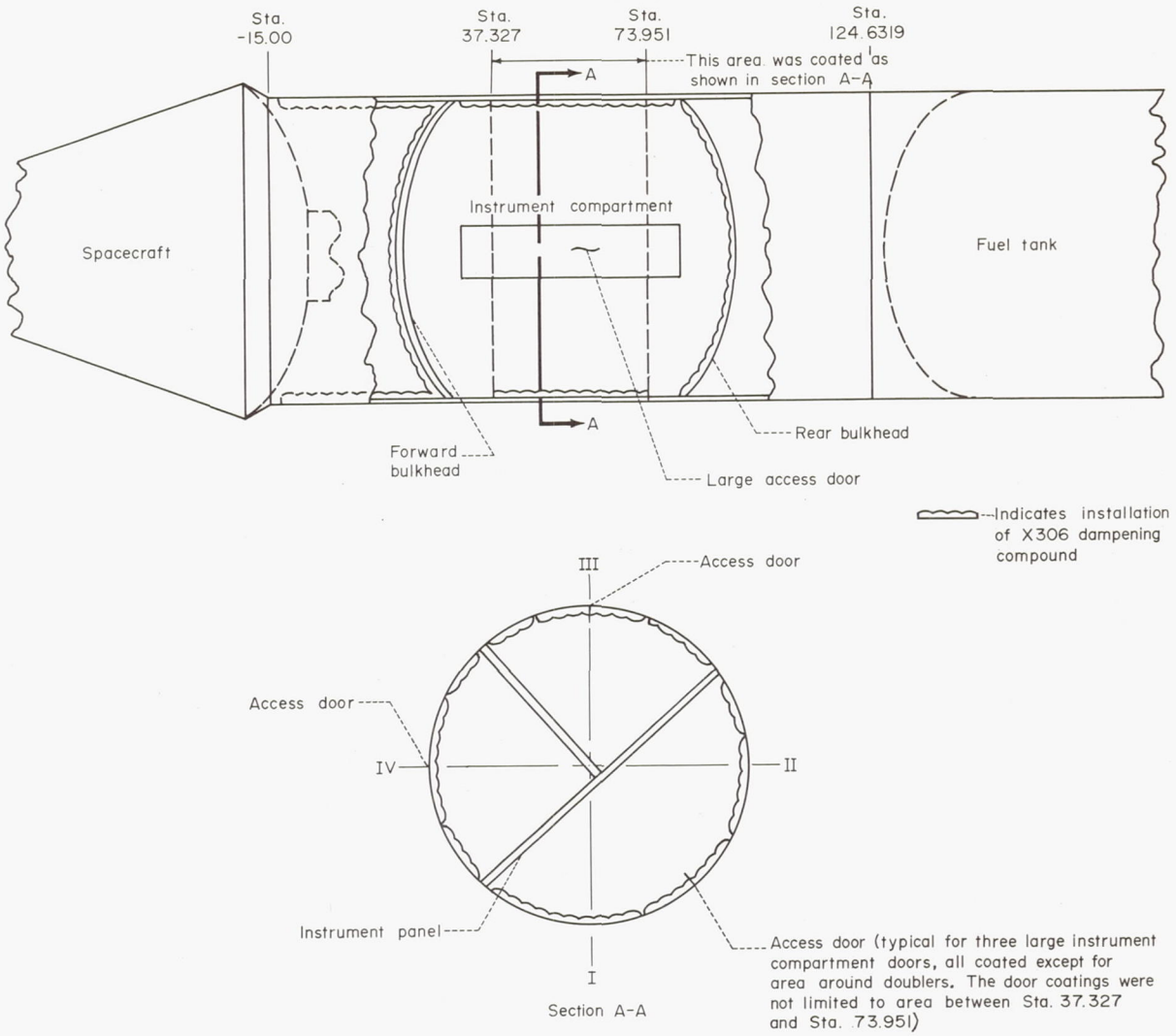



FIGURE 4–12.—Installation of dampening compound in instrument compartment and adapter section for Mercury-Redstone 4 (MR–4).

thrust controller ran above nominal resulting in propellant depletion 0.5 second before abort pressure sensor deactivation. The abort system was able to sense this early shutdown and aborted the spacecraft. The above normal cut-off velocity, combined with the thrust of the escape motor caused the spacecraft to land well beyond the intended recovery area. The simple timing changes explained previously were made to take care of higher propulsion system tolerances.

MR–BD was launched on March 24, 1961, to evaluate a filter network added in the launch vehicle control circuit and modifications incorporated to eliminate the overspeed condition experienced on MR–1A and MR–2. The filter network was intended to dampen the effect of the second bending mode frequency (6 to 10 cps) on the pitch and yaw loop. The flight went exactly as expected and proved the effectiveness of this change.

MR–3 was the first manned flight. With Astronaut Alan Shepard as the pilot, the spacecraft lifted off at 9:34 a.m. e.s.t. on May 5, 1961. All objectives assigned to the launch vehicle were successfully accomplished and no system malfunction occurred. During powered flight,

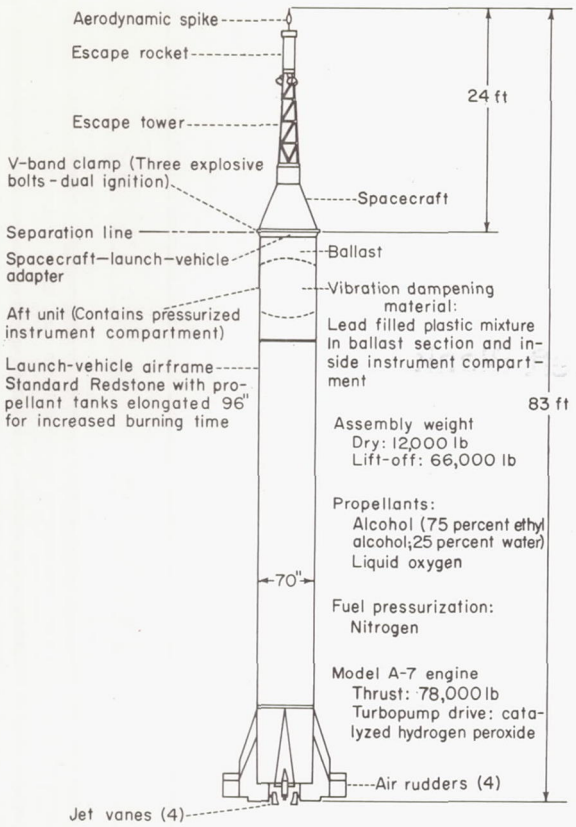



FIGURE 4–13.—Mercury-Redstone configuration.

the astronaut reported buffeting. However, telemetry data indicated lower vibrations than on earlier flights. To reduce these vibrations, additional dampening material was added to the instrument compartment prior to the remaining flight.

Concluding the Mercury-Redstone program was MR–4 carrying Astronaut Virgil I. Grissom in the second manned suborbital space flight. Again, all launch-vehicle systems worked properly and all objectives were achieved. Improved vibration reports indicated that the additional dampening material added to the instrument compartment proved effective.

The Mercury-Redstone flight program was concluded on a positive note with the successful MR–4 mission on July 21, 1961. The first manned flight into space had been accomplished by MR–3 in just over 2½ years from the project's initiation. The initial objectives of providing space flight familiarization and training for astronauts had been accomplished. The spacecraft was exposed briefly to space flight conditions. Of equal importance was the invaluable training of the ground crew in the preparation, launching, and the recovery of a manned spacecraft.

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# 5. MERCURY-ATLAS LAUNCH-VEHICLE DEVELOPMENT AND PERFORMANCE

By Lt. Colonel C. L. Gandy, Jr., *Space Systems Division, U.S. Air Force;* and Major I. B. Hanson, *Space Systems Division, U.S. Air Force*

**Summary**

In this paper the overall Atlas launch-vehicle program in support of Project Mercury is discussed. The paper includes the areas of both management and operations. Implications to be drawn from the presentation are that sound planning by experienced Air Force personnel early in the program; strong top-level management support; great attention to engineering, manufacturing, and operational detail; and strong individual motivation have been responsible for the success of this portion of Project Mercury. The procedures used in the launch-vehicle program were not conceived or promulgated by any one individual overnight. Rather, they grew from the experience of many and were further shaped by the program itself as it progressed.

## Introduction

This paper presents the management aspects of the launch-vehicle system in redirecting a ballistic-missile weapon system into a launch-vehicle system for manned space research. Early agreements between the U.S. Air Force and the National Aeronautics and Space Administration (NASA) established the program responsibilities and identified the management interfaces. Specific guidelines were laid down by the Air Force Chief of Staff to provide effective support to NASA within the military framework of what was then known as the Air Force Ballistic Missile Division. Definitive policies were established to insure maximum launch-vehicle safety for the pilots. The initial overall Mercury systems engineering as it affected the launch vehicle was performed by U.S. Air Force/NASA technical panels and then gradually shifted to the Air Force and its technical contractor, Space Technology Laboratories, and more recently the Aerospace Corporation, for more specific systems engineering.

The basic Atlas "D" system as it existed at the beginning of the program is described to provide a basis for the explanation of the launch-vehicle modifications that were required to support the mission. A brief description is given of the problems that were associated with the individual launch-vehicle flights and the results of the postflight evaluations. A more detailed postflight evaluation is given of the MA–9 flight.

## Program Management

During the mid–1950's, the U.S. Air Force conducted a number of studies dealing with manned space flight. Many plans had been formulated and several of the programs had reached a detailed development plan state when, in August 1958, the President directed the assignment of the man-in-space effort to the National Aeronautics and Space Administration. On October 7, 1958, the Space Task Group was organized at Langley Field, Virginia, to manage the then established and later named, Project Mercury.

During the period from October 1958 until April 1959, a series of meetings took place between NASA and the Air Force Ballistic Missile Division to define the AFBMD support required by the NASA-Space Task Group. The problems considered included: definition of the scope of NASA's effort, definition of launch-vehicle requirements, definition of procurement procedures, launch schedules, and launch facilities. It is interesting to note that at the time of the first NASA visit to AFBMD on October 23, 1958, the proposed program envisioned over 25 flights using the Redstone, Thor or Jupiter, and Atlas launch vehicles. Space-

craft orbital weight was to be approximately 2,100 pounds for a 120 nautical-mile orbit. Additional meetings culminated in the issuance to AFBMD of NASA Order HS–24 on November 23, 1958, which specifically requested that the Air Force supply one "C" series Atlas to support Project Mercury. The order specified that this was the initial request of a proposed program which would require approximately 13 boosters of the Atlas and Thor class. On December 8, 1958, AFBMD received NASA Order HS–36 which requested nine "D" series Atlas boosters. Subsequent amendments to HS–36 deleted HS–24, changing the total requirements to 10 Atlas "D" vehicles, later to 14 "D's," eliminating the Thors. Further discussions between the two agencies resulted in the agreement that the Air Force would have full responsibility for the development, procurement, production and launch of the Atlas vehicles for Project Mercury (see fig. 5–1). The final meeting of this series was held between General Schriever, then Commander AFBMD, and Dr. Glennan, Administrator of NASA, on April 7, 1959, in Washington. The basic memorandum of understanding between NASA and the USAF grew from this conference.

A program office was established within the AFBMD to manage the launch vehicle effort, and the services of the Space Technology Laboratories (STL) were requested within the framework of the Atlas weapons system program to support Mercury. Specific guidelines were laid down by the Commander of AFBMD in order that maximum responsiveness to NASA requirements could be assured.

The early systems engineering was accomplished within the framework of technical panels established by NASA. Participants in the panel work were drawn from various NASA organizations, McDonnell, AFBMD, STL and the Atlas manufacturer, General Dynamics/Astronautics. Once the initial problem areas had been defined, technical panels were subdivided into working groups with specific technical areas assigned to assure that thorough treatment was given to all engineering problems. Through the medium of the technical panels, basic trajectory conditions were developed. The launch-escape system concept was born and specific requirements were developed. Reliability goals were established, and systems restraints were imposed. In order to implement, in detail, the general systems approach developed through the technical panels, the Air Force called upon STL to perform these tasks. It was necessary to institute a special systems engineering and technical direction effort for the Mercury/Atlas program, and the STL Mercury Project Office was established in the Fall of 1959 under the direction of Mr. B. A. Hohmann. In the summer of 1960, when the Aerospace Corporation was organized, the task was transferred to this new organization. The majority of the STL Mercury office personnel transferred to Aerospace continued to perform their original jobs. The basic responsibilities of the systems engineering and technical direction group were to develop the technical requirements, monitor the systems and launch-vehicle development, provide trajectory calculations and guidance equations, analyze both ground and flight-test results, assure production acceptability of the launch vehicle, assist in administering the pilot safety program, and provide systems integration of the Atlas associate contractor's systems.

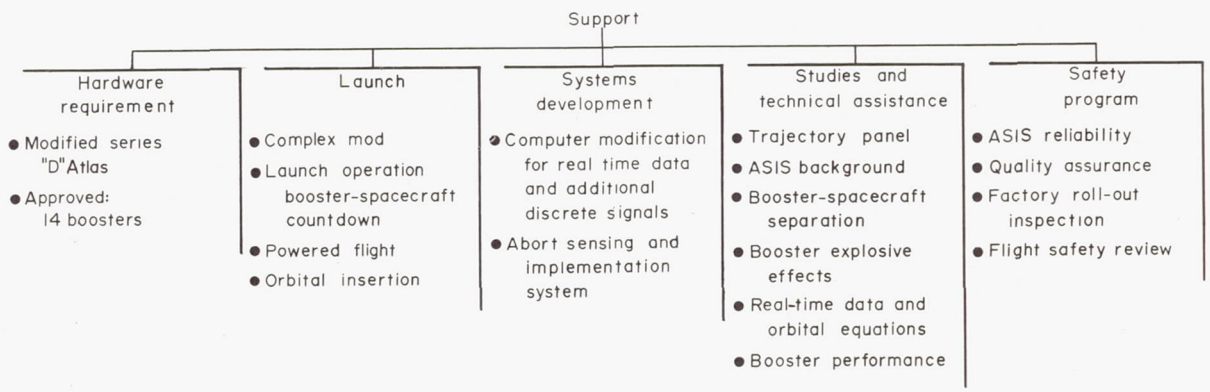



FIGURE 5–1.—Space Systems Division support.

The Space Systems Division and the Aerospace Corporation program offices together were the focal point for detailed management of the launch vehicle program. Program requirements reached this level along a formal path (see fig. 5–2) established from Headquarters NASA to Headquarters USAF, to the Air Force Systems Command (AFSC), to Space Systems Division (SSD), to the Deputy for Launch Vehicles (SSV) to the program offices. A shorter and less formal but equally binding path existed from Manned Spacecraft Center directly to the program offices. Direction received along either path was translated by the program office personnel into action items and routed to the proper agency for accomplishment. Contractual direction and configuration management were controlled by the SSD Program Office originally through the Atlas Weapons System Program Office and later through the SSD Standard Launch Vehicle III (SLV III) Office. Subsystem offices within SSD were responsive to the Mercury launch vehicle program office in the areas of guidance and propulsion systems. Technical direction was handled informally by direct contact between the Aerospace program office and the contractors and formally through the SSD program office.

The Atlas associate-contractor team consisted of General Dynamics/Astronautics (GD/A) who furnished the Atlas airframe and basic vehicle, Rocketdyne Division of North American Aviation (R/D) who furnished the propulsion system, General Electric (GE) who provided both the airborne and ground portions of the guidance system, and Burroughs Corporation who provided the A–1 Computer for in-flight guidance in conjunction with the GE system. GD/A performed the launches at the Atlantic Missile Range (AMR) under the supervision of the 6555th Aerospace Test Wing, and the other contractors provided appropriate launch services. Other valuable members of the Atlas team were the Air Force's Western and Eastern Contract Management Regions whose personnel insured the contractors' compliance with contract provisions and performed quality control and technical inspection functions.

Early in the Mercury program, Major General O. J. Ritland, as Commander of BMD recognized that a safety program should be instituted to protect the Mercury pilot. Accordingly, he directed that studies be conducted to determine what efforts were required to insure

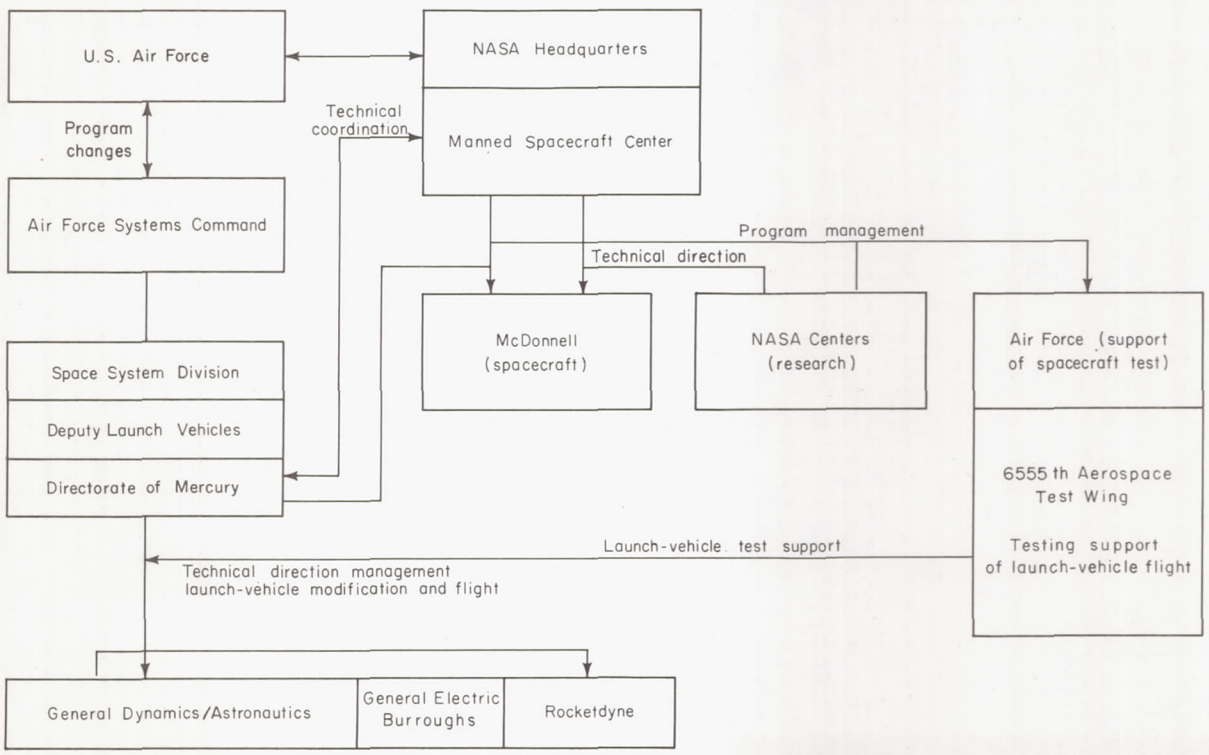



FIGURE 5–2.—Management responsibilities.

safe powered flight and to assure the program management that the launch vehicle was indeed ready for manned flight. This study resulted in the Pilot Safety Program for Mercury-Atlas launch vehicles (see fig. 5–3), a program which has dominated the management of the launch-vehicle portion of Project Mercury.

The basic objectives of the program have been to assure design reliability and adequate pilot safety. Recognizing that the Atlas had been designed as a weapons system and had not been required to meet the reliability expected of a manned system, program personnel established these objectives. The first was to be met through quality of production and end-product excellence. The quality of production would be assured through education and motivation of all personnel associated with manufacture of the hardware, through special component selection and marking procedures, and through special handling techniques. End-product excellence could be assured by requiring that no shortages would be tolerated at the time of launch-vehicle acceptance, and that the vehicle must be complete and up to date with no provisions for field modifications. This assurance would be gained by means of a detailed and highly critical factory roll-out inspection. The inspection would be conducted by experienced and well qualified personnel from both the Aerospace and SSD program offices. NASA observation was invited.

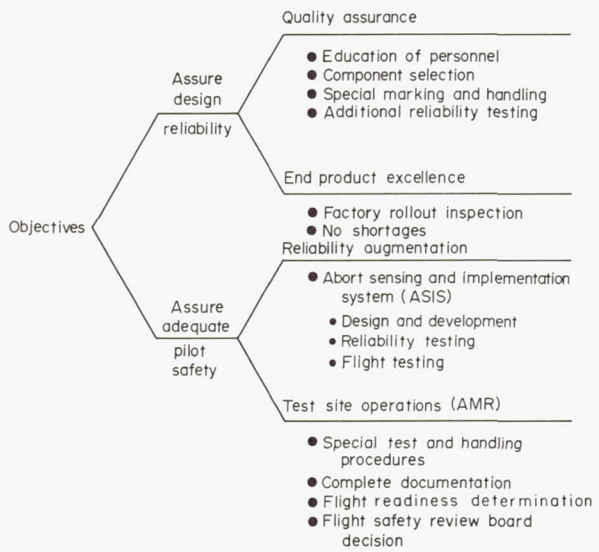



FIGURE 5–3.—Pilot-safety program.

The second objective of assuring adequate safety would be met by providing reliability augmentation and by special test-site operations. The abort sensing and implementation system (ASIS) was designed to bridge the gap between the existing reliability of the launch-vehicle and the near perfection required of a manned system. The ASIS was an automatic system designed to sense an impending catastrophic failure and initiate spacecraft escape prior to the failure. The ASIS itself had to be an extremely reliable system. This reliability was obtained first through a design based upon redundant sensors and circuitry. Then rigid design reviews, stringent ground testing, and finally flight testing were conducted for the system.

The special test-site operations started with unique Mercury handling procedures for the launch vehicle and a requirement that complete documentation be maintained on all prelaunch operations. The documentation, in turn, led to assurance that the vehicle was indeed flight ready upon completion of the required prelaunch testing. The flight readiness was certified by the Mercury–Atlas Flight Safety Review Board. This board was established as a high-level Air Force and Aerospace board chaired for all manned flights by the Commander, SSD.

### Basic Atlas Description

At the time of the original NASA order for Mercury–Atlas launch vehicles in the fall of 1958, the U.S. Air Force development flight test program was principally concerned with the Atlas "C" model. The "D" model (see fig. 5–4) which was scheduled to begin testing in 1959, was considered the operational system and was therefore selected as the most suitable for use as the Mercury launch vehicle. The following paragraphs give a general description of the basic Atlas "D" vehicle from which the launch vehicle for the Mercury spacecraft was developed.

The Atlas launch vehicle comprises of two main sections, the body or sustainer section and the aft or booster-engine section. The booster-engine section is connected to the sustainer thrust ring by a mechanical system which permits separation. The Atlas is considered a 1½-stage missile in that only the boost engines and

associated hardware are jettisoned at the completion of the first stage of firing.

The sustainer section is made up of a thin wall, fully monocoque structure pressure vessel and derives its rigidity from internal pressurization. The sustainer body is a welded structure of corrosion-resistant stainless-steel sheets varying in thickness from 0.048 inch to 0.015 inch. The tank is approximately 50 feet in length. The forward end consists of a thin dome on which the liquid oxygen boil-off valve is mounted. The base of the dome is joined to the first skin of a conical section whose upper diameter is approximately 70 inches. The conical section joins a cylindrical section 10 feet in diameter. The lower end of the tank is conical, tapering to a point. A hemispherical diaphragm called the intermediate bulkhead divides the tank into a forward section for liquid oxygen and an aft section for RP–1 fuel. A thrust ring joins the conical aft section to the cylindrical portion of the tank. Annular baffles in the tanks serve to dampen propellant sloshing. The sustainer engine with its associated equipment and subsystems is gimbal-mounted to the sustainer thrust cone which is the aft end of the fuel tank. Vernier engine thrust chambers are gimbal-mounted on opposite sides of the structure at the extreme aft end of the cylindrical portion of the tank. Equipment pods containing electronic and electrical units are attached to the tank skin 90° around the tank from the verniers.

The aft section or booster-engine section consists of two booster engines, structure, and associated equipment. It is attached to the thrust ring at the aft end of the tank section by a mechanism which releases it for separation. The motion of this section is controlled during separation by jettison tracks. A radiation shield protects the aft section from the heat radiated from the engine exhaust.

The propulsion system consists of a Rocketdyne MA–2 rocket-engine group made up of two main assemblies: the booster section (see fig. 5–5) consisting of two booster engines having 154,000 pounds of thrust each and the sustainer-vernier group (see fig. 5–6) consisting of

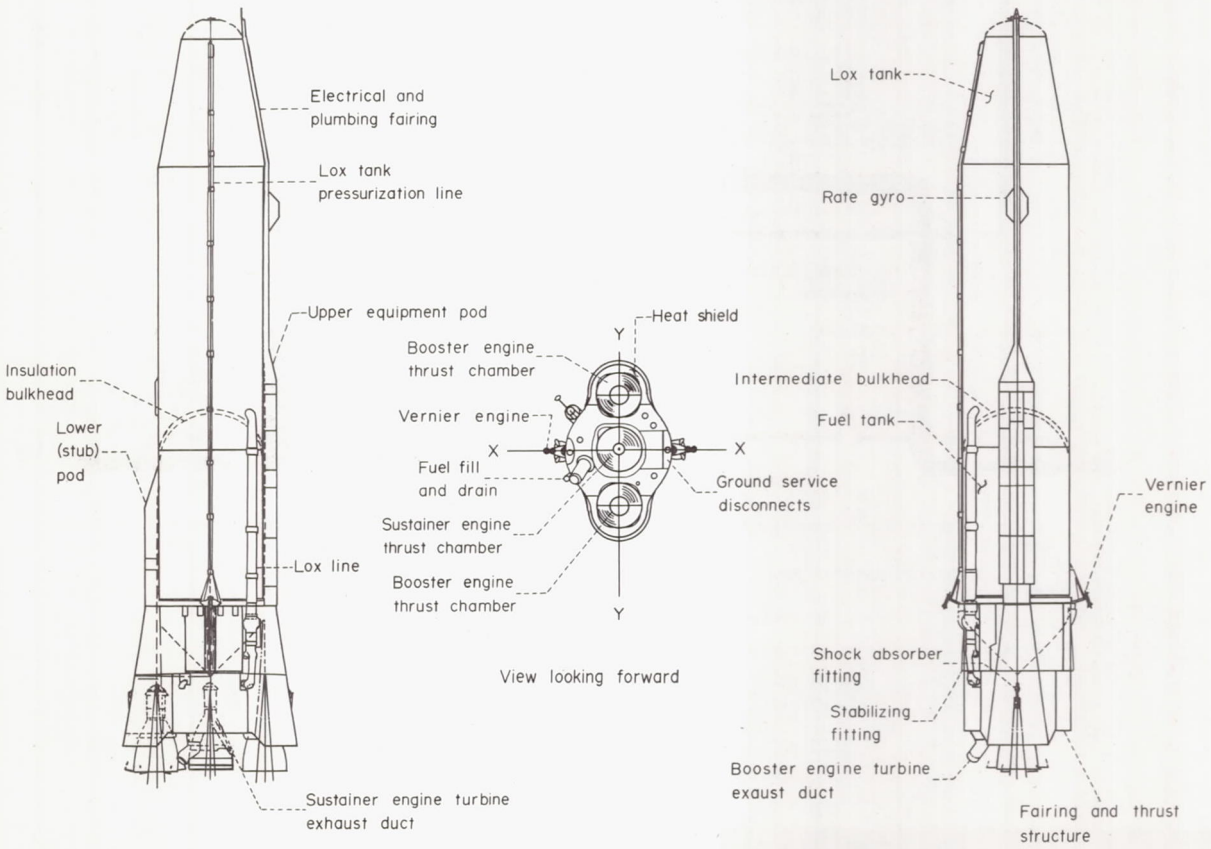



FIGURE 5–4.—Three-view drawing of basic Atlas configuration.

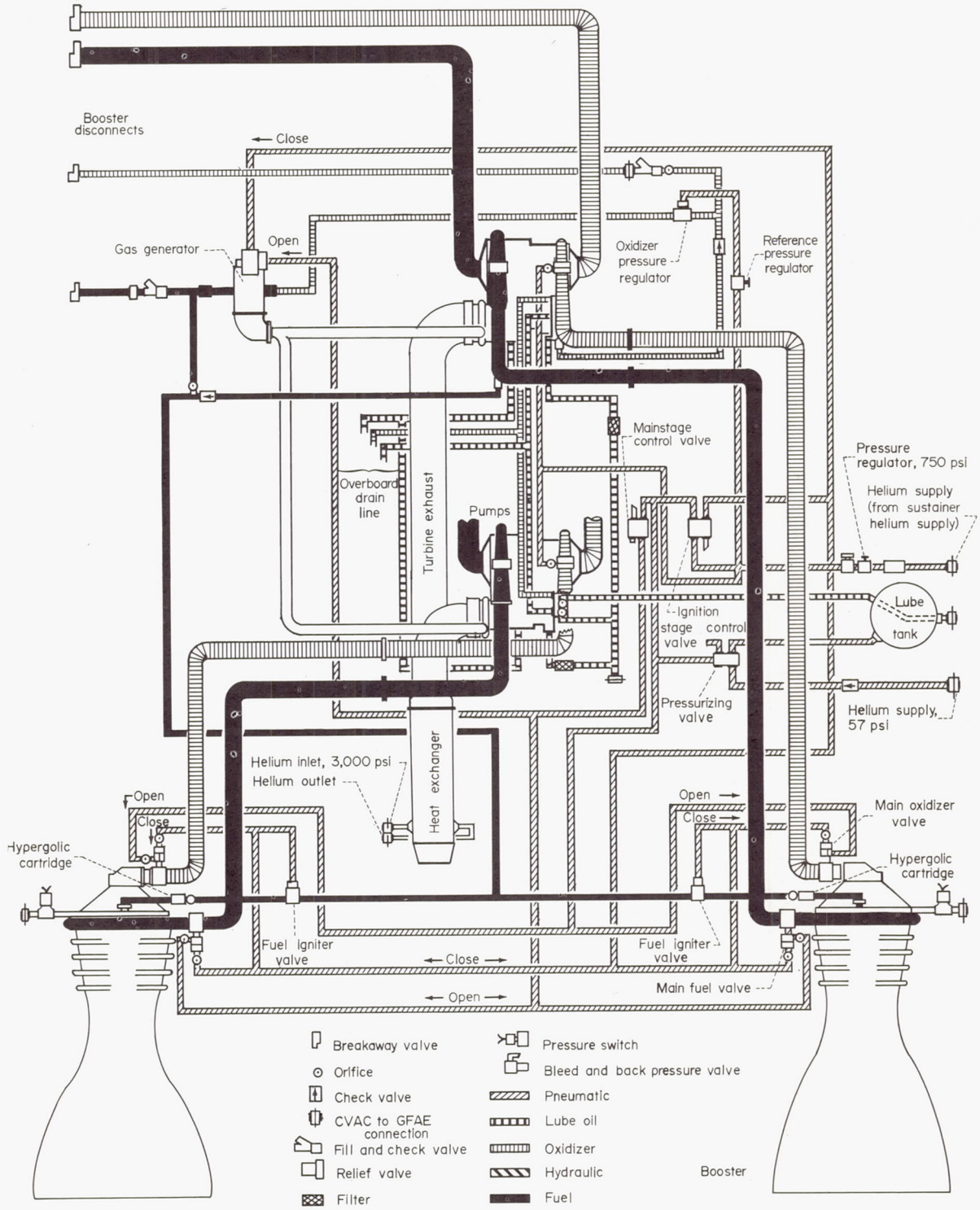



FIGURE 5–5.—Propulsion system for booster engines.

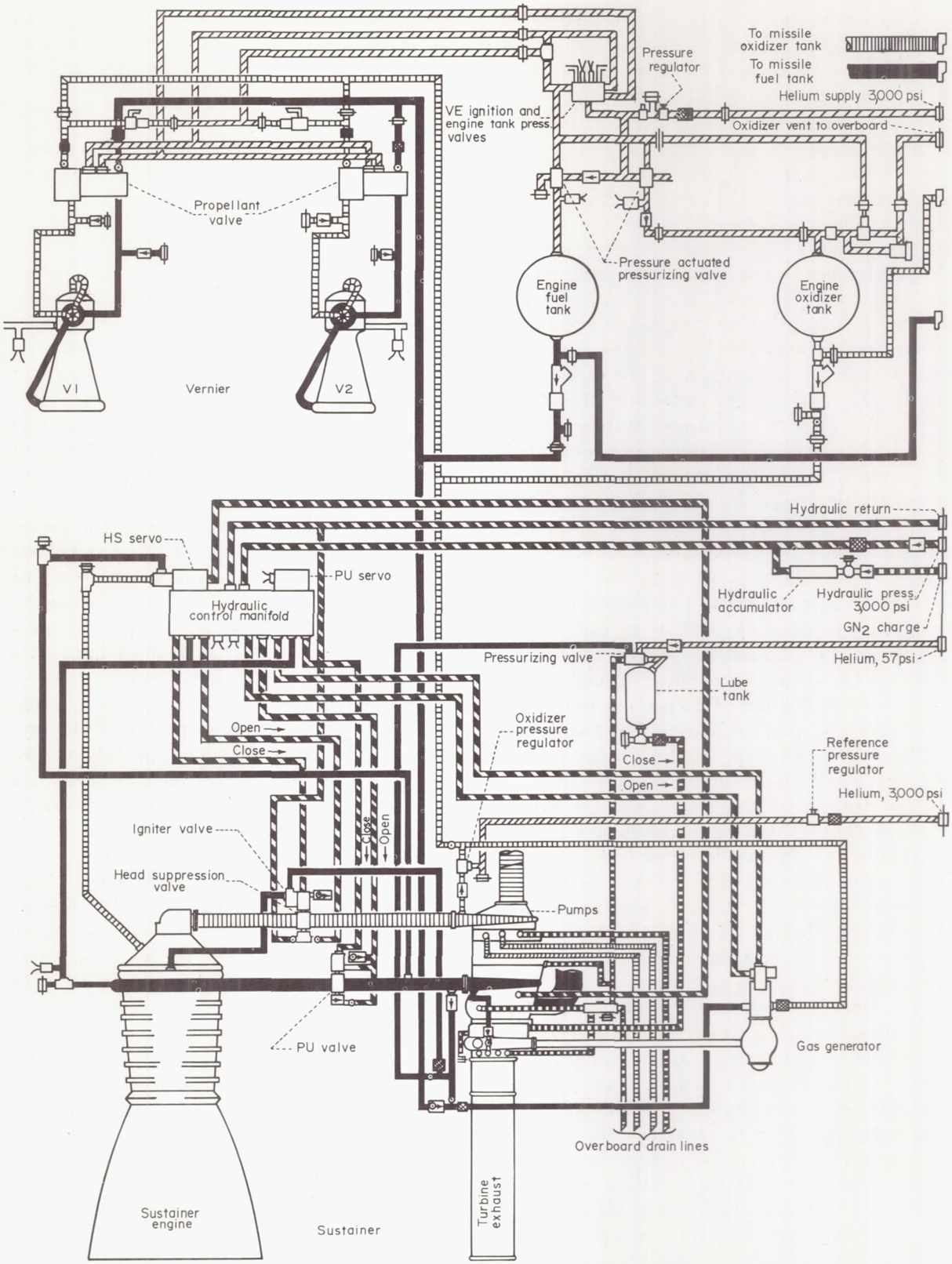



FIGURE 5–6.—Propulsion system for sustainer engines.

one sustainer engine having 57,000 pounds of thrust and two vernier engines having 1,000 pounds of thrust each. All are single-start, fixed-thrust rocket engines utilizing liquid oxygen and a liquid hydrocarbon fuel (RP–1) as propellants.

The booster engine is composed of two identical thrust chambers and a power package. Two dual turbopumps in the power package deliver the propellants under high pressure to the thrust chamber. The turbopumps are driven by high-speed turbines, energized by high-velocity gas supplied by a single gas generator. The power package also includes the hydraulic pump used for lubrication of the turbopump gears. The booster gas generator consists of a spherical combustion chamber and an exhaust manifold. After start, liquid oxygen and fuel are supplied to the combustion chamber under pressures developed by the turbopump. The combustion gases are routed to the turbopump turbine wheels by the exhaust manifold after which the gases pass through the heat exchanger to heat and expand helium for vehicle-system pressurization and then are vented overboard. High-pressure propellants exiting from the turbopumps are routed through valves which control the flow of propellants to the fuel manifold and oxidizer dome. The two thrust chambers are bell shaped and made up of tubes running lengthwise from the top of the chamber to the bottom of the skirt. Fuel is routed through these tubes to cool the chamber walls. A pyrotechnic igniter initiates combustion of the fuel-oxidizer mixture. Thrust loads are transmitted to the missile through gimbal mounts on each chamber allowing the chambers to be swiveled a maximum of 5° in pitch and yaw about the vehicle centerline.

The sustainer engine is gimbal mounted to the thrust cone of the fuel tank. The assembly is similar to that of the booster engines. The sustainer engine dual turbopump supplies propellants to the vernier engine in addition to the sustainer engine. The sustainer engine fuel-lox mixture is continuously controlled during flight by the Propellant Utilization Subsystem (PU) in order to maintain optimum mass ratio of the propellants and thus reduce unusable residuals to a minimum. The sustainer engine gimballing is controlled in pitch and yaw within an arc of ±3°. The sustainer engine is used for steering only after the booster engines have been shut down. The sustainer is operated throughout the flight and is at full thrust at lift-off.

The vernier engines are installed on the aft airframe in two separate units. Propellants for starting the vernier engines are provided by pressurized start tanks and are supplied by the sustainer turbopump for the remainder of the flight. The thrust chamber is double walled and also contains fuel for cooling of the thrust chamber walls. The vernier engines provide roll control throughout flight; pitch and yaw control during staging; and pitch, roll, and yaw during the vernier solo phase during flights in which this phase of operation is utilized. Mercury-Atlas vehicles do not have a vernier solo period. The chamber can be moved through an arc of approximately 140° in pitch and 50° in yaw.

The automatic start sequence of the rocket engines is accomplished by initiating propellant flows into the thrust chambers, the firing of igniters, and the burning through of igniter detector links. These must be accomplished in the proper sequence and total time, or automatic shutdown of the engine will occur.

A propellant utilization system shown in figure 5–7 is used to effect emptying of the propellant tanks as nearly simultaneously as possible. This subsystem continuously senses the mass of the propellants remaining in the tanks and computes the error resulting from a comparison of the mass ratio of the remaining propellants with a nominal mixture ratio. This error signal then adjusts the rate of fuel flow by repositioning the sustainer-engine fuel-control valve to allow the burning of more or less fuel in order that the required mass ratio can be maintained. This assembly is made up of two manometers, each enclosing a mandrel coated with a dielectric material, and a computer-comparator. The unit senses the propellant masses by functioning as a variable capacitor by area contact with a column of mercury balanced against the liquid-propellant head in each tank. The mandrels are shaped in such a way that the capacitance is analogous to the mass of propellant remaining in each tank.

The airborne pneumatic system provides the structural rigidity for the main propellant tanks and also provides the necessary head to

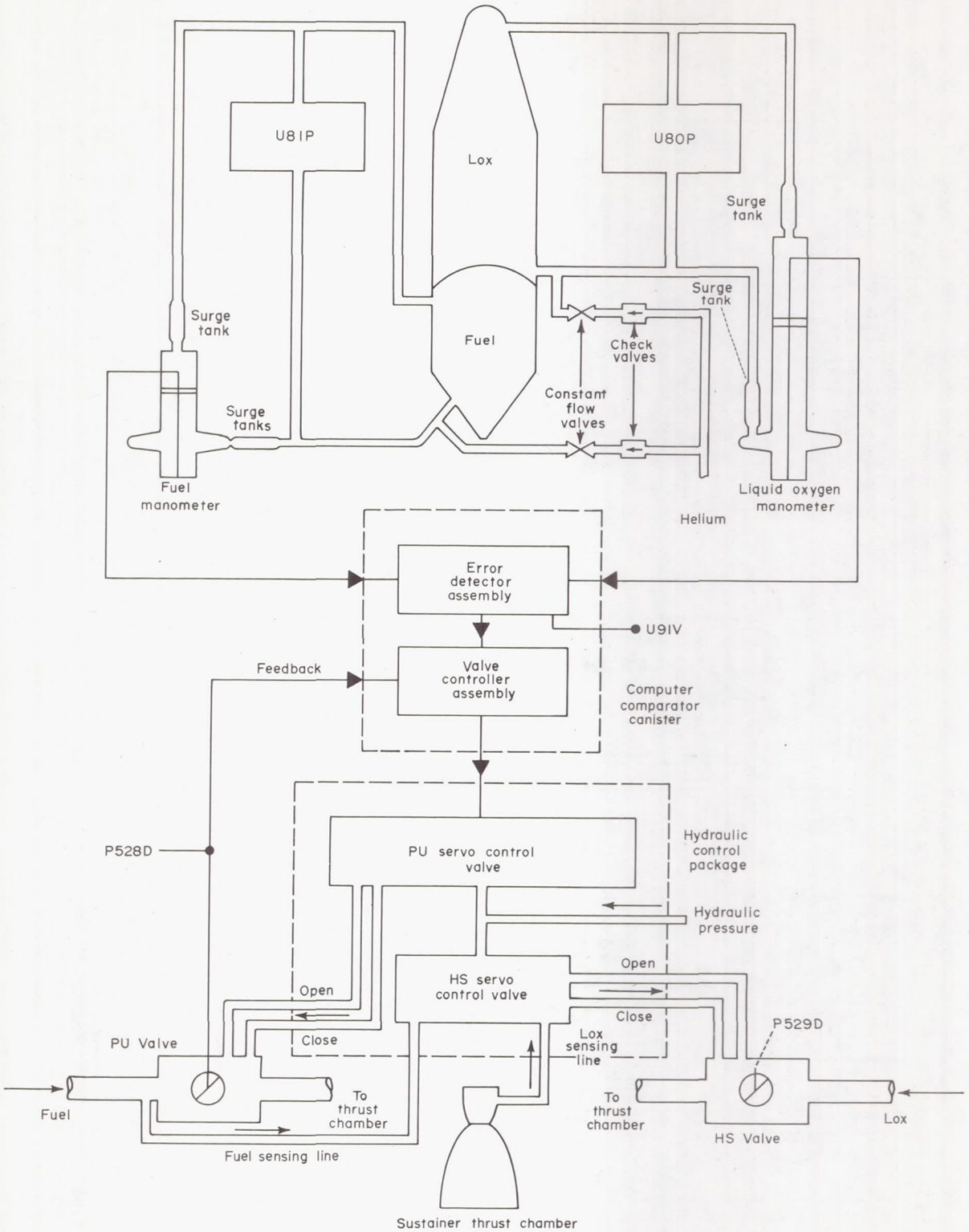



FIGURE 5–7.—Propellant utilization system.

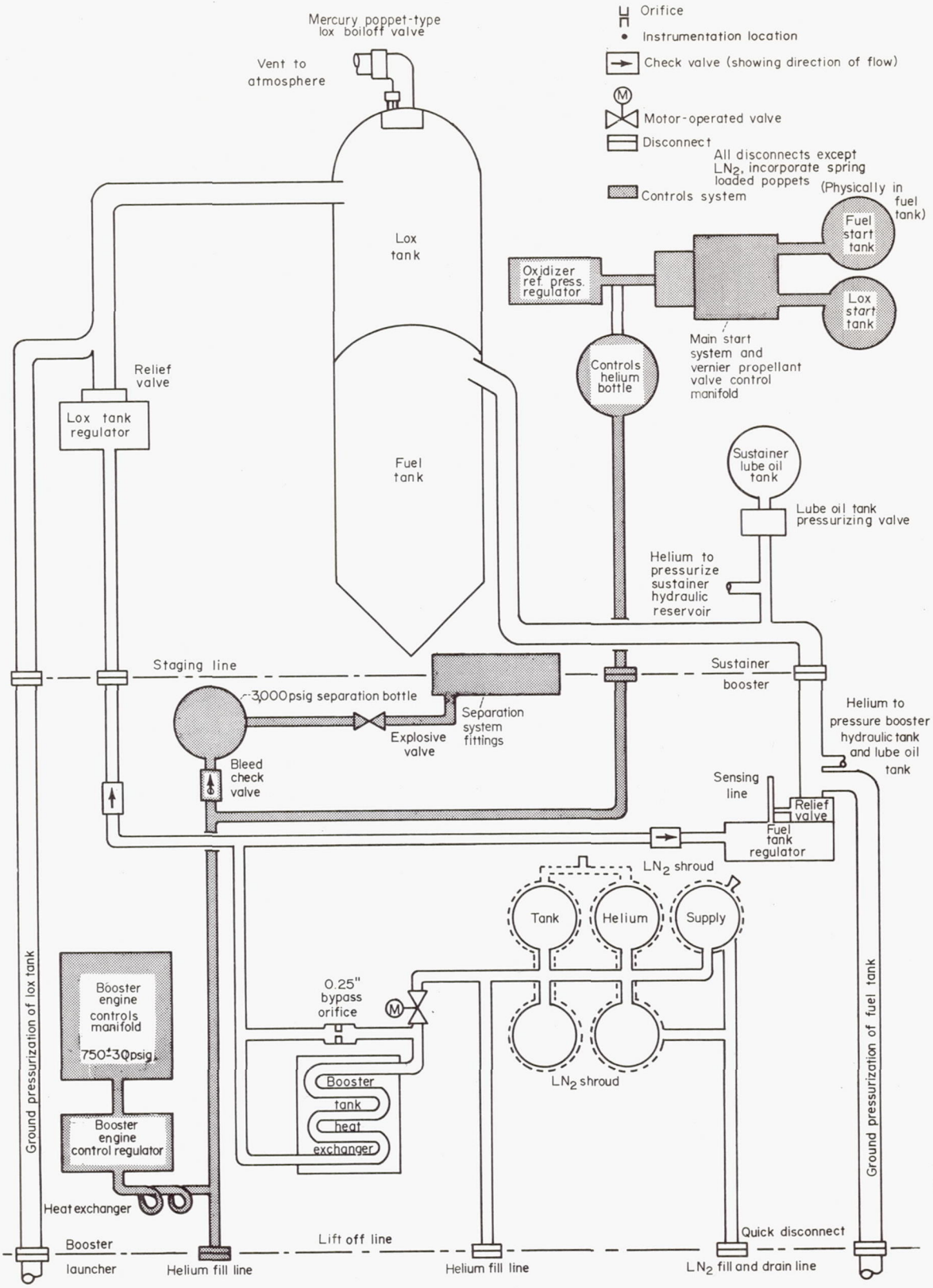



FIGURE 5–8.—Pneumatic system.

prevent the turbopumps from cavitating at low acceleration levels. This pneumatic system, presented schematically in figure 5–8, is used throughout the missile for control, reservoirs, lubricant tanks and the pressurization of the vernier engine propellant tanks. The pneumatic system also provides the actuation force for the first stage separation latches. The pressurization medium is helium, and liquid nitrogen is used to refrigerate the vehicle borne helium supply during the prelaunch phase of the countdown. Five spherical titanium storage vessels are used for the primary supply and are jettisioned with the booster section at staging. The control helium bottle is retained with the sustainer section and provides control pressure for the sustainer section. Tank pressurization is maintained by helium throughout booster-engine operation only. After first stage separation, no helium is required since oxidizer vaporization will keep the pressure in the oxidizer tank above the allowable minimum limits, and main fuel-tank pressure decay will not reduce this pressure beyond the minimum of allowable limits throughout the remainder of the flight. A liquid-oxygen tank boil-off valve is used to maintain proper cryogenic conditions of lox during tanking and holds.

The electrical subsystem (see fig. 5–9) is composed of a 28 v d-c main missile battery and a 115 v d-c three-phase 400 cps inverter. Battery power is provided to the inverter, propulsion subsystem, flight control subsystem, propellant utilization system and abort sensing and implementation system (ASIS). A power changeover switch is used to transfer both a-c and d-c

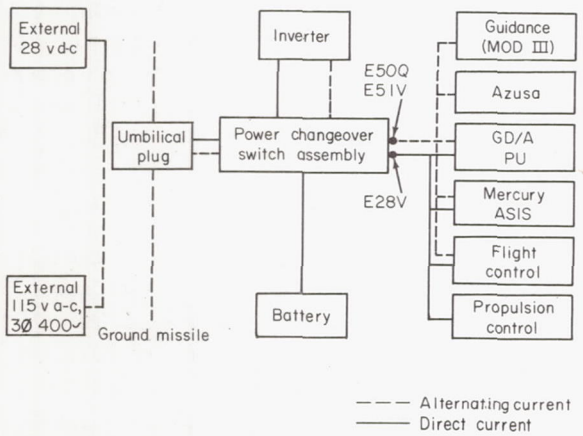



FIGURE 5–9.—Electrical system.

power from external to internal. The position of this switch is manually selected in the launch control blockhouse. The main battery is a remotely activated unit consisting of 20 silver zinc cells connected in series and housed in a sealed canister. The inverter is a rotary-type inverter using a magnetic amplifier voltage and frequency regulator and associated noise filters. The inverter is three phase-WYE connected.

The flight control subsystem consists of a flight programer, an autopilot, and 10 gimbaled thrust-chamber actuator assemblies. The subsystem stabilizes and steers the vehicle along the desired flight path by controlling the direction of the engine thrust vectors. Steering commands are generated on the onboard flight programer during the boost phase. Shortly after first-stage separation, the airborne portion of the guidance subsystem is enabled to provide steering commands to the autopilot for the remainder of the sustainer phase. The autopilot (see fig. 5–10) consists of a gyro package, a servo amplifier package, a programer, an excitation transformer, and engine-position feed-back transducers. On the standard Atlas "D", the main gyro package is located at station 991 and contains three rate gyros, three displacement gyros, and associated electronic equipment. The programer is a transistorized electrical timing device which controls the various flight sequential functions such as roll and pitch programs, staging filter changes, guidance enable, and so forth throughout the entire flight. The programer has two major sequences, the first of which is initiated at 2-inch motion of the missile and the second at receipt of the staging command from the ground-based portion of the guidance subsystem. The servo-amplifier package provides the integrating circuits and includes the necessary filters to insure proper flight attitudes and rates.

The guidance subsystem (see fig. 5–11) consists of the ground-based General Electric Mod III–A X-band radar system, the Burroughs A–1 computer system, and the airborne General Electric Mod III–A guidance group. The Mod III system consists of a position-tracking radar subsystem which determines the position vector of the missile with respect to the guidance station, plus a rate subsystem, which by Doppler techniques measures the missile velocity. In addition, the tracking radar serves as a data

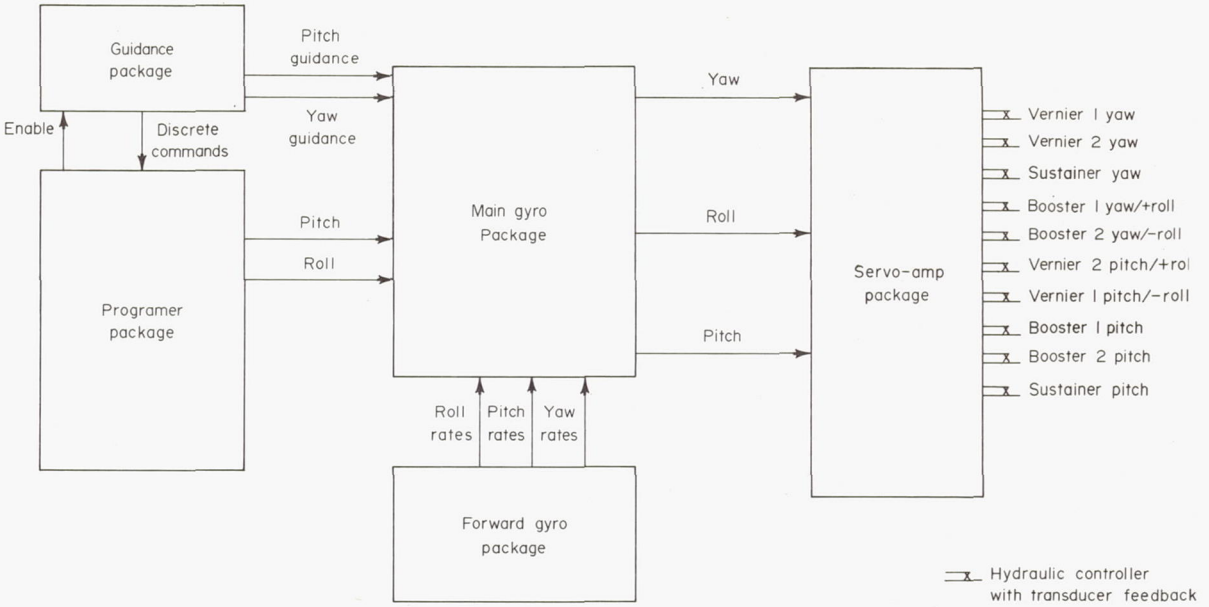



FIGURE 5–10.—Flight control system.

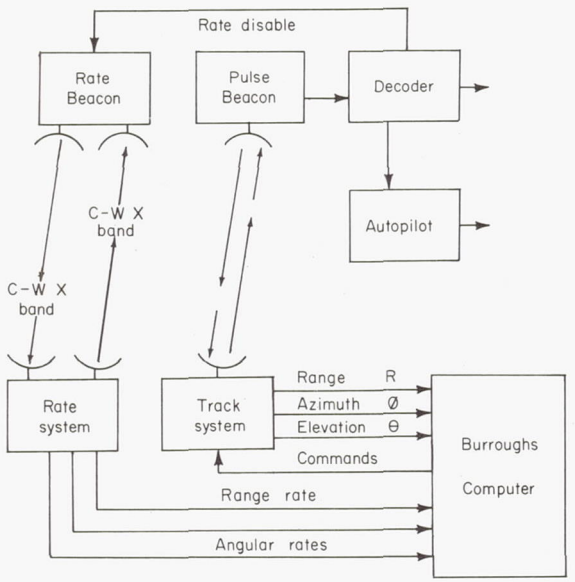



FIGURE 5–11.—Guidance system, MOD III.

link to provide operational commands to the missile-borne equipment. Position and rate data from the radar are transmitted to the Burroughs A–1 computer for processing in accordance with the guidance equations. The computer generates corrective commands which are then fed back into the radar to be transmitted as steering signals to the launch vehicle.

Although weapon-system Atlas vehicles do not require telemetery transmission, research and development vehicles have such a requirement. Two telemetry subsystems were used on Mercury flights. The standard subsystem was used on flights through MA–4 (Atlas 88D). Subsequent flights utilized a lightweight telemetry subsystem (see fig. 5–12) which will be described in the next section.

Two additional systems are installed for the use of range safety personnel. The first is the range safety command system which receives, decodes, and activates the arming, engine shutdown, and destruct functions. The other system is the Azusa radio tracking system which monitors launch vehicle space position and velocity. The Azusa system data are sent to the Atlantic Missile Range IBM 7090 computer which continuously predicts the instantaneous impact point (IIP) of the launch vehicle.

### Atlas Modifications For Mercury

The Atlas "D" vehicle had been chosen for the task of launching Mercury on the basis of its being the most reliable launch vehicle available with the requisite performance during the time period of the program. It was not possible to start at that point to design a "man-

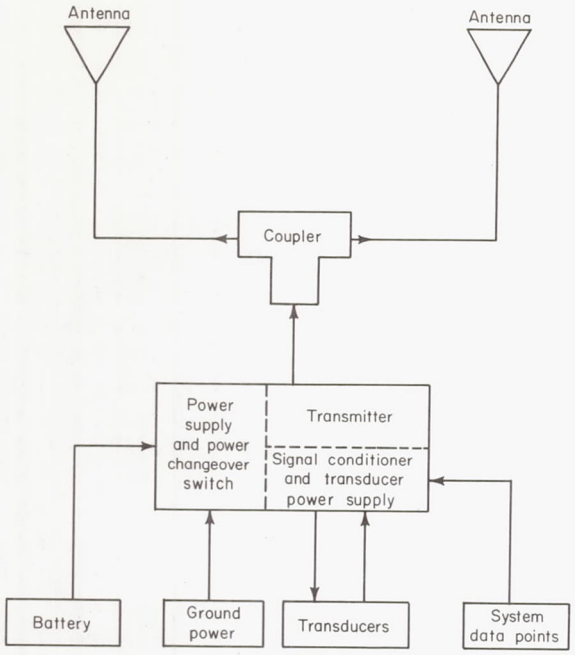



FIGURE 5–12.—Lightweight telemetry system.

rated" vehicle to perform the Mercury flights without several years' delay to the program. Therefore, to capitalize on the reliability inherent in the basic design of the vehicle which had been demonstrated in Atlas development flight tests, a ground rule of the booster program was to make a minimum number of changes to the launch vehicle. Only those changes necessary to adapt the vehicle to the requirements of the Mercury mission or those required to improve the safety of the vehicle for manned flight would be authorized. As with any development program, flight-test experience established the need for incorporation of additional modifications with the major purpose being the enhancement of reliability and pilot safety. It should be recognized, however, that an extremely conservative approach was taken with regard to such changes. Modifications required extensive ground testing, and no critical modification to be used in a manned flight was incorporated until it had been successfully flown on at least one other Atlas. The following paragraphs describe the major system modifications incorporated in Mercury-Atlas launch vehicles. These changes are shown schematically in figure 5–13.

In the first category of changes required by the Mercury mission, one of the most important of the changes was the addition of a new auto-

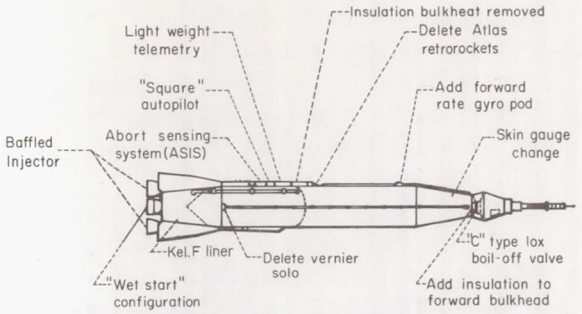



FIGURE 5–13.—Launch-vehicle modifications for Mercury.

pilot rate gyro package in a position considerably ahead of that used on the standard Atlas "D". This addition was dictated by the longer Mercury payload and its effect on the flexible Atlas tank during flight. The modification provided optimum attitude rate sensing with resulting minimum engine deflections for more efficient performance of the launch vehicle. The standard rate gyro installation was retained for abort system sensing.

Additional changes in this category include the deletion of the vernier solo phase of operation and relocation of the retrorockets from the launch vehicle to the spacecraft for use as posigrade rocket motors. In the vernier solo mode of operation the vernier engines remain in operation after sustainer engine cut-off, which allows very delicate adjustments to vehicle velocity. Deletion of this mode permitted a reduction in weight and mission complexity with a resultant improvement in performance and reliability. Relocation of the retrorockets was feasible since the Mercury spacecraft was lighter and the posigrade rockets would thus be more efficient in separating the spacecraft from the launch vehicle. The standard Atlas used these retrorockets to "back off" the launch vehicle from the payload. This relocation of the Atlas retrorockets to the spacecraft retropack required that the thin skin of the lox dome be protected from the rocket exhaust. This was accomplished by developing a fiberglass shield that attached to the mating ring and covered the entire dome. A wet-start technique was also incorporated in the engine starting sequence to minimize starting transients. Another change required for the Mercury mission affected the guidance system. Because the trajectory of the Mercury-Atlas flight differed greatly from that

of the weapon system vehicles, new guidance antennas were required to insure maximum signal strength throughout powered flight. Extensive theoretical and model work was required to develop antennas which would have suitable radiation patterns.

By far the most important change made to the Atlas in support of Project Mercury was the development and installation of an entirely new system, the Abort Sensing and Implementation System (ASIS). This system was designed to bridge the gap between the admittedly less than perfect reliability of the basic Atlas weapon system design and that near-perfect reliability desirable for a manned flight system. From a very searching and thorough analysis of Atlas flight data, it was seen that certain missile parameters deviated from a norm sufficiently ahead of catastrophic failure to be used as warnings. It was decided to develop an extremely reliable automatic system to monitor these parameters and to signal the spacecraft escape system when a catastrophe was imminent.

The parameters that were considered the most significant for abort indications (see fig. 5-14)

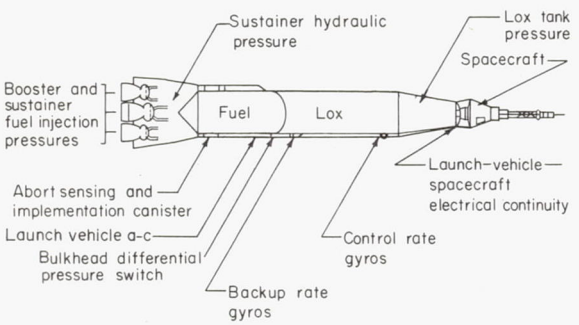



FIGURE 5-14.—Abort system sensors for Mercury-Atlas launch vehicle.

were the liquid oxygen tank pressure, the differential pressure across the intermediate bulkhead, the missile attitude rates about all three axes, rocket-engine injector manifold pressures, sustainer hydraulic pressure, and the launch-vehicle a-c power. Dual sensors for each of these parameters were incorporated into the Atlas system and operation outside a predetermined tolerance band then caused the ASIS to drop out the 28 volt power being supplied to the catastrophic failure detection relays. This drop-out of voltage provided an additional measure of safety in that if the abort sensing system failed in itself, the loss of power to the spacecraft would also cause an abort. This system was developed at GD/A under the direction of the Air Force and its systems engineering contractor and with the coordination of the NASA Manned Spacecraft Center group. This subsystem with its sensors was flown "piggyback" on Atlas research and development vehicles prior to the first Mercury-Atlas flight at which time it was flown in the open-loop configuration. The first closed-loop flight of this system was the MA-3 mission. The flight very successfully demonstrated the capability of the ASIS when the launch vehicle was destroyed by the range safety officer. The ASIS satisfactorily signaled an abort to the spacecraft in sufficient time to permit adequate separation of the spacecraft from the Atlas explosion.

To provide additional safety measures with the automatic abort, commanded abort, and range safety command destruct, a 3-second delay was incorporated between the signal that commanded engine shutdown and the signal that ignited the destruct package on the launch vehicle. With this change, the launch vehicle could not be destroyed by command for a period of 3 seconds after the engines were shut down. This delay was incorporated to provide adequate separation of the spacecraft from the launch vehicle prior to a command destruct. To provide protection to the launch area, a lockout was incorporated from lift-off to 30 seconds that prevented an abort command from signaling engine shutdown. The spacecraft launch-escape motor had sufficient thrust to provide adequate separation from the Atlas during this period. Immediately after the failure of the MA-1 (Atlas 50D) mission, a special board was convened to investigate the cause of the failure. A number of separate phases of investigation were performed under the direction of the board. These included extensive analyses by Aerospace and GD/A of the thermal environment, discontinuity stresses, and aerodynamic loads. Wind-tunnel tests were performed to gain more knowledge of the aerodynamic conditions imposed on the total flight vehicle in the transonic and maximum dynamic-pressure regions. Analyses conducted by NASA Space Task Group personnel indicated the possibility of concentrated loads being introduced into the

Atlas through the forward structural ring which mated with the spacecraft adapter. None of the investigations or analyses were able to pinpoint the exact cause of the initial failure of the vehicle, but there was no question of the fact that the failure had occurred in the area of the forward lox tank and the spacecraft adapter.

Because of the failure of MA–1 in July 1960 and the successful flight from a structural standpoint of Big Joe I (10D) in September 1959, a coordinated decision was made by BMD and NASA to increase the thickness of the four forward skins of the Atlas lox tank on future Mercury-Atlas launch vehicles to approximately the same dimensions as those on 10D. At the same time it was agreed that the spacecraft adapter would be stiffened. In order to fly the MA–2 mission with Atlas 67D, a thin-skinned vehicle, without undue delay a temporary modification was made. A stainless steel reinforcing band was installed about the lower flange of the mating structure (Station 502 ring) and the first skin aft.

Early in the Mercury program, it was decided to incorporate the electronic "square" autopilot in place of the electromechanical "round" autopilot. The reason for selecting the relatively new electronic system over the proven round autopilot was to obtain improved reliability, improved maintainability due to modular plug in packaging, much increased flexibility to allow for most types of mission changes, and ease of manufacturing by eliminating much of the hidden, point-to-point wiring, and the mechanical setup of the programer. The improved reliability was a result of including such design features as electronic switching in place of mechanical switching, electronic integration in place of electromechanical integration, and improved circuit board design.

Initial flight testing in the Atlas program was accomplished by using an early type of telemetry system. The weight and power requirements to operate the early system were high, and oscillator stability degraded over a short operating time span. A transistorized, lightweight system was developed by GD/A to support the Centaur flight test programs and appeared to be well suited to the Mercury program (fig. 5–12). NASA requested the Air Force to incorporate the new lightweight system as soon as practicable. This system was first flown on launch vehicle 100D.

Normal cut-off of the sustainer and vernier engines is initiated by a discrete signal from the Burroughs computer to the ground guidance station. The ground guidance station then retransmits this signal to the airborne decoder which in turn signals engine shutdown. A partially redundant path for the sustainer-engine cut-off (SECO) discrete transmission was developed early in the program. This path enabled the Burroughs computer to forward the signal to the launch vehicle through the range safety command transmitter, to the airborne receiver and then to the engine relay control. This path was not wholly redundant because no duplication existed in the computer function for generating the SECO time; therefore, a single failure mode still remained. As a result, discussions with the AMR range personnel brought out the capability of the Azusa system to provide a completely redundant SECO discrete signal. The Azusa system in conjunction with the IP 7090 computer continuously computed the instantaneous launch-vehicle impact point (IIP) for Range Safety purposes. With certain modifications to the IP 7090 program it was possible to obtain the time at which orbital velocity was attained. This time was provided electrically by land line to the NASA Flight Director. The Flight Director used this signal as a backup in the event of a failure or malfunction of the Mod III guidance system. This backup SECO system was susceptible to guidance noise; therefore, it was discontinued after the MA–8 mission.

The SECO discrete transmitted to the launch vehicle through the range safety command system as described above, was originally tied to the output of the guidance decoder which obtained a SECO discrete through the guidance system. Both SECO signals used the same path from the guidance decoder and the range safety command receiver to the engine shutdown relays. Additional engineering was required to reroute the signal to provide a completely redundant path.

It is pointed out later in the paper that a problem was discovered with the guidance system at low antenna elevation angles. After a thorough study of the hardware involved, it

was concluded that the excessive noise in received signals was cyclic in nature and was caused by an as yet undetermined atmospheric phenomenon. To reduce the effect of the noise in the over-all guidance loop, first the guidance equations were modified to provide additional smoothing, and second, the rate station base legs were increased from 2,000 to 6,000 feet. Although the latter modification did not reduce the actual noise being received, the deleterious effect of the noise on the received signals was reduced by approximately 3 to 1. The third and more complex phase of the study was the development of a mathematical model of the noise to permit a more detailed analysis of the trajectory equation changes that were necessary to minimize this effect. These changes were made to the guidance equations and used on the MA–9 mission.

A fuel tanking test that was being accomplished between the first and second launch attempts of the MA–6 mission brought out a problem that necessitated a major airframe change. The plastic foam material that is used for insulating the base of the liquid oxygen tank from the fuel tank is contained between two hemispherical bulkheads which separate the lox and fuel. A more detailed description of this problem is contained in a description of the MA–6 mission. The limited need for the insulation material coupled with the undesirable feature of removing the bulkhead in the field indicated the need for eliminating the insulation bulkhead from all future Mercury vehicles. A change in the production line stopped further installations of this material.

A major modification in the propulsion system was required to eliminate the possibility of combustion instability. Early in the Atlas program, it was found through flight test experience that combustion instability in the booster engines could cause catastrophic failure of the entire missile. The probability of the occurrence was low; however, the need for maximum safety in the manned space program dictated the need for corrective action. Initially, rough combustion monitors were incorporated and the Atlas was held down for an additional period of time, to allow sensing of the engine vibration characteristics. A rough combustion cut-off (RCC) system then would automatically shut down the engine if combustion instabilities occurred. Again, a thorough ground and flight test program was required before installation on Mercury–Atlas launch vehicles. Another modification provided redundancy in the electrical portion of the propulsion system to insure engine shutdown at SECO. Action was taken also to reroute electrical circuitry to insure proper valve sequencing during start in the high-pressure liquid oxygen plumbing.

Another major modification was made to the booster engine turbopumps. Flight and component testing experience show that incidents had occurred where the lox pump impeller had rubbed against the inlet adapter of the pump. This rubbing caused sufficient heat to ignite the lox and in some cases cause an explosion in the turbopump. Extensive analyses and tests could not pinpoint the exact cause for rubbing; however, the effect of the rubbing could be eliminated by lining the inlet adapter with a plastic material. Months of component and system testing and engineering review were required to provide positive assurance of the suitability of this modification.

Limited changes were made to the pneumatic system specifically for Mercury. Considerable effort was expended however on analyzing tank pressure oscillation that occurs during lift-off under certain payload conditions. The necessary precautions were taken until this problem was resolved. To resolve the entire problem a complex computer model was developed to represent the dynamic conditions existing in the pneumatic system and structure of the Mercury-Atlas vehicle. It was found at the conclusion of the study that earlier characteristics of the helium regulator which controls pressurization gas to the oxidizer tank tended to drive the system into a resonant condition. The new regulator that was used with Mercury did not have the unstable characteristics; therefore, flight restrictions were removed.

The propellant utilization (PU) system was modified to insure an outage of lox rather than fuel in the event abnormal flight characteristics caused the vehicle to expend the total propellant. Early studies had indicated that a safer engine shutdown would be possible in this propellant depletion shutdown case if the lox supply was the first to be consumed. The PU system normally monitors the propellant levels to maintain the proper ratio of onboard pro-

pellants. For the Mercury-Atlas the system was modified to drive the mixture ratio to the lox-rich condition at 10 seconds prior to SECO to reduce the ratio of lox to fuel. More recently, a revised method of calibration and a slightly modified mandrel have been developed to provide a more accurate method of maintaining proper propellant ratios.

A normal phenomenon associated with the Atlas vehicle is a roll oscillation that occurs with the missile as the vehicle becomes free of the launcher mechanism. Ordinarily this roll is of small magnitude, and quickly corrected as the autopilot is enabled. A review of flight test history showed that certain vehicles were displaced at roll rates which approached the abort threshold established for the ASIS in roll. Two parallel studies were accomplished to review this problem area. One study reevaluated the abort thresholds to determine if the roll rate limit could be increased. The other study attempted to determine the cause for the roll oscillation in order that a proper modification could be made. It was determined that limited opening of the threshold in roll could be accomplished. The study into the cause for the roll included developing a mathematical model of the launcher mechanism, analysis of control forces required to rotate the missile similar to that demonstrated in flight, base recirculation, engine alinement, and a review of engine acceptance data at Rocketdyne. It was readily apparent that the canted turbine exhaust duct contributed to the clockwise roll moment. This force could cause only half of the roll moment experienced by the missile. Acceptance data from the engine supplier showed that a group of 81 engines had an average roll moment in the same direction of approximately the same magnitude as that experienced in flight. Although the acceptance test-stand and flight-experience data on individual engines did not correlate, it was determined that offsetting the alinement of the booster engines could counteract this roll moment and minimize the roll tendency at lift-off. This change was flight tested and found to correct the roll moment satisfactorily; therefore, the change was incorporated for MA–9 in Atlas 130D.

## Flight Test Summary

### Big Joe

The first Mercury-Atlas launch was that of Big Joe 1, Atlas number 10D, on September 9, 1959. Atlas 10D was built originally as an R and D vehicle but had received the initial Mercury modifications. The payload was a boilerplate spacecraft. The purposes of the flight were to test the spacecraft's ablative heat shield, afterbody heating, reentry dynamics, attitude control and recovery capability.

Two flight readiness firings (FRF) were performed on Big Joe 1. The first, on September 1, 1959, ended immediately after T–0 because the ignition stage delay timer commanded shutdown of the rocket engines when neither sustainer nor main engine ignition followed normal vernier ignition. There was no booster or stand damage. The second FRF was successfully completed on September 3, 1959, with normal ignition, transition to main stage and shutdown by the engine timer after approximately 19 seconds of running time.

During the launch on September 9, 1959, engine ignition, thrust buildup and lift-off were normal, and launch vehicle performance was completely satisfactory throughout the booster phase. However, after booster engine cut-off (BECO) the booster section failed to jettison and remained attached to the vehicle for the duration of the flight. The sustainer continued to power the vehicle until propellant depletion some 14 seconds prior to normal cut-off. The malfunction resulted in the vehicle failing to achieve planned maximum velocity and in exceeding planned maximum altitude.

Although the injection conditions were considerably different from the preplanned values, the spacecraft reentry satisfied the NASA test objectives. By extrapolating the acquired data, NASA Space Task Group was able to derive the information which was required for spacecraft design. The spacecraft was recovered and returned to Cape Canaveral. Since the data from Big Joe 1 satisfied NASA requirements, a second Mercury launch, Big Joe 2 (Atlas 20D), which had been scheduled for the fall of 1959, was cancelled and the launch vehicle was transferred to another program.

### MA–1

The first of the Mercury-Atlas series, MA–1, was launched at 8 : 13 a.m. e.s.t. on July 29, 1960, from AMR Launch Complex 14. The vehicle consisted of Atlas 50D and Mercury Spacecraft number 4, the first production spacecraft, and adapter. The spacecraft primary test objectives concerned structural integrity, afterbody heating and reentry dynamics from a temperature critical abort. Launch vehicle objectives concerned the capability to release the spacecraft at the desired insertion conditions and the evaluation of the open-loop operation of the Abort Sensing and Implementation System (ASIS). A single successful FRF was accomplished on July 21, 1960.

Lift-off and flight of the vehicle were nominal until 57.6 seconds after lift-off when a shock was registered by both the launch vehicle and spacecraft axial accelerometers. The vehicle at that time was at approximately an altitude of 30,000 feet and 11,000 feet down range. The sequence of sensing of the shock indicated that the disturbances occurred in the area of the adapter and the forward portion of the lox tank. All Atlas telemetry was lost at 59 seconds, which is believed to be the time of final missile destruction. Spacecraft telemetry however, continued until 202 seconds, which was the time of landing on the sea, approximately 5 miles downrange. The only launch vehicle primary test objective accomplished was successful evaluation of the open-loop performance of the ASIS which generated an abort signal at 57.6 seconds due to loss of normal a-c voltage.

The failure investigation and results are discussed in the section *Atlas Modifications for Mercury* in this paper.

### MA–2

The MA–2 mission was flown by using the Atlas 67D and a production Mercury spacecraft. Test objectives for this flight were concerned with the ability of the spacecraft to withstand reentry under the temperature-critical abort conditions and with the capability of the Atlas to meet the proper injection conditions. This Atlas "D" modified for the Mercury mission, was unique in the program in that it incorporated a stainless steel reinforcing band installed around the vehicle between stations 502 and 510. A thin sheet of asbestos was installed between the reinforcing band and the tank skin. This modification was installed as a precaution against the type of failure which had occurred on the previous MA–1 flight. Atlas 67D had accomplished a successful Flight Readiness Firing on November 19, 1960.

Launch countdown was satisfactory. Although 70 minutes of hold and recycle time were required, none of this time was required for the launch vehicle systems. Lift-off occurred at 9 : 10 a.m. e.s.t. on February 21, 1961. Ignition and transition to main stage were normal, and lift-off was clean. The launch-vehicle flight was uneventful. All test objectives were fully met, and the spacecraft was successfully recovered. This launch was the first one which was preceded by a full Flight Safety Review Board in accordance with the Mercury-Atlas Booster Pilot Safety Program.

### MA–3

Atlas 100D, the launch vehicle for the MA–3 mission, was launched from Complex 14 at AMR at 11 :15 a.m. e.s.t. on April 25, 1961. The mission was terminated by the range safety officer after approximately 43.3 seconds due to failure of the launch vehicle to follow its roll and pitch programs. Although the launch-vehicle was destroyed as a result of a malfunction, considerable benefit was derived from the flight test. First, the satisfactory closed-loop performance of the ASIS was demonstrated when the booster engines were shutdown and escape rocket ignition was initiated automatically by the ASIS. The escape was so successful that the spacecraft was recovered some 20 minutes after launch and reused on the next flight.

Second, because of the nature of the failure an intensive reexamination of the complete electrical circuitry and its design, manufacture and installation for both the launch complex and the Atlas was conducted. The malfunction which caused flight termination was isolated to the flight programer or associated circuitry. The programer either failed to start or started and then subsequently stopped without initiating the roll and pitch program. The programer was subsequently recovered, examined, and tested. The most probable cause of the flight failure was traced to contamination of one of the programer pins which under vibration could have caused the failure. The extensive review

that was conducted to analyze the flight failure also revealed other deficiencies in the flight control systems. Changes were made to the system to eliminate these possible failure modes and to improve the over-all system reliability.

### MA–4

On August 24, 1961, the Flight Safety Review Board for the MA–4 mission (Atlas 88D) performed a thorough review of all pertinent problem areas and all recent Atlas flight test problems. At the completion of the meeting, the Flight Safety Review Board approved the use of Launch Vehicle 88D for the MA–4 mission. The launch was delayed for a 1-week period, and during this period of time a transistor malfunction in one of the flight control canisters aroused considerable concern. An investigation into the factors associated with this failure necessitated an Air Force Program Office decision to delay the flight in order that flight control equipment could be reworked to eliminate this failure mode. The contractor responded to this decision with a concentrated effort to rework and test the equipment in time to support a mid-September launch. On September 12, 1961, the Flight Safety Review Board reconvened. The flight control canister rework was reviewed in detail and the Board concluded that 88D was suitable for launch. The 88D was scheduled for a 250-minute countdown starting at 2:50 a.m. e.s.t. on September 13, 1961. There were four holds and a recycle which resulted in a total count of 374 minutes. Propulsion system performance was normal throughout the start sequence, additional hold-down period and flight. Thrust chamber vibration levels were normal during the hold-down period and chamber pressures were nominal. Lift-off occurred at 9:04 a.m. e.s.t. The flight control systems satisfactorily generated the missile roll and pitchover programs and responded correctly to guidance discrete and steering commands. An oscillation in the pitch plane was evident from T+15 seconds to T+21 seconds. Missile bending was evidenced by an accelerometer located on the lox-dome, launch-vehicle flight control rate gyros, and by spacecraft rate gyros. A change to a launch-vehicle automatic hydraulic actuator had been incorporated on the MA–4 launch vehicle, and the flight control gains had been modified. A postflight modal analysis of the MA–4 data showed that marginal stability characteristics existed with these changes; therefore, additional filtering was deemed to be necessary for future Mercury flights. Propellant slosh amplitudes during the booster phase were low and considerably less than that observed on launch vehicle 67D. The spacecraft injection conditions on the flight of 88D were of the poorest quality of all Mercury-Atlas flights. Tolerance limits were not exceeded; however, a thorough study was required to determine the cause. An analysis of the flight data brought to light tracking phenomena associated with low incident angles. Under certain conditions the guidance system could be affected by varying atmospheric refraction towards the end of flight when the vehicle was approaching the horizon. Limited experience had been obtained at these low elevation angles with the Mod III guidance system. A continuing study was conducted by SSD, GE, Aerospace Corporation, and Space Technology Laboratories in conjunction with the AF Electronic System Division and its technical staff to determine the source and limitations of this phenomenon. Knowledge gained from this study was later used to rewrite the trajectory equations to reduce the effects of refraction anomalies. The postflight evaluation of the launch vehicle 88D mission indicated that all flight objectives were successfully achieved.

### MA–5

On November 28, 1961, the Flight Safety Review Board met to consider all aspects of the MA–5 (93–D) mission. Included in the Board review were the autopilot changes that resulted from the previous flight and a thorough discussion of the activities and studies conducted in the evaluation of the guidance phenomena. Additional problems associated with other Atlas space and weapons flight test were reviewed. The Board committed the vehicle to launch.

A number of holds were required during the countdown on November 29, 1963. The data link between the GE ground guidance station and the Mercury Control Center dropped out temporarily, requiring a 4-minute hold, and a 3-minute hold was called at T−7 minutes to resolve a pulse beacon anomaly. Ignition and transition into mainstage were accomplished satisfactorily and within expected limits. There was no indication of the pitch oscillation observed on the launch of 88D. Following

lift-off a slight oscillation was noted in the pitch channel during the roll program which is common to all launches. The usual flight oscillation due to slosh was observed from T+86 seconds to T+100 seconds. Staging transients were normal. Approximately 30 seconds before sustainer engine cut-off, a slight oscillation appeared in the pitch channel. This condition persisted for 15 seconds, but the magnitude of the oscillation was of no significance. All flight test objectives were met and the performance of the launch vehicle was within expected tolerance limits.

**MA–6**

The historic flight of Astronaut John Glenn was conducted on board Atlas launch vehicle 109D and Mercury Spacecraft number 13. This was the flight for which the Atlas Pilot Safety Program had been conceived and for which the launch vehicle team had been preparing so long. Major General O. J. Ritland, then Commander, SSD, convened the Fight Safety Review Board on January 26, 1962, to determine the suitability of Atlas 109D for support of the MA–6 mission. In addition to reviewing the readiness of 109D, the Board reassessed the critical problem areas in the development of the Atlas in support of the Mercury program. This reassessment included all major developments, flight-test incidents and corrective action, the results of additional reliability tests and analyses conducted specifically for Mercury, the performance and test status of the abort system, performance margins experienced on past flights and the prediction for MA–6, the configuration differences between the previous Mercury vehicle and 109D, and the production and test history of 109D prior to its arrival at AMR. One minor, last-minute problem with a faulty pin connection in the staging umbilical necessitated a second session of the board on January 26, 1962. The condition was repaired, and a complete series of tests to validate all the pin connections in the connector was satisfactorily accomplished. After the second session the Board committed 109D for the launch of MA–6. Adverse weather in the launch area forced the cancellation of the first launch attempt on January 27, 1962. After a tanking test was conducted on January 30, fuel was detected in the insulation bulkhead located between the fuel and liquid oxygen tanks. The insulation bulkhead is located beneath the intermediate bulkhead that structurally separates the two tanks and is composed of a plastic foam material vented to the fuel tank and supported by a thin steel membrane. Test of the plastic material indicated that sufficient fuel could be retained in the insulation material to overload the membrane supporting the insulation bulkhead under flight accelerations. Inasmuch as it was not possible to assess the amount of saturation accurately, a decision was made to remove the insulation material and the supporting structure. The extent of the repair on Atlas 109D at AMR constituted a major but necessary rework of the vehicle in the field. Because of the extent of the repair a highly qualified group of personnel from Aerospace, 6555 ATW and GD/A were selected as a special committee to review all procedures associated with the task. This group also was responsible for validating of the complete task. The primary reason the task was authorized as a field modification was because it had been successfully performed in the field only weeks before on Atlas 121D, the Ranger 3 launch vehicle which flew successfully.

The combined Atlas-Mercury countdown was begun at 11:30 p.m. e.s.t. on February 19, 1962. A built-in hold of 90 minutes was scheduled to begin at T−120 minutes. At T−280 minutes, a telemetry check indicated the Azusa impact predictor was "no-go." The ground station was checked and found to be operating satisfactorily. The tower decks around the transponder were raised, but still the Azusa system could not achieve a satisfactory lock. A decision was made to change the transponder which was accomplished by T−273 minutes. The test was resumed and Azusa was declared "go" at T–213 minutes. No hold time was involved. At T−149 minutes, during the flight control system test, there was a sudden drop in the rate beacon automatic gain control (AGC). The first backup beacon was substituted for the original unit during the built-in hold. This hold was extended for 30 minutes and then extended another 15 minutes to complete installation and retesting. Ten additional minutes of hold were required for the spacecraft. At T−60 minutes a 30-minute hold was requested by Mercury Control Center which was then extended an additional 5 minutes. At T−45 minutes a 15-minute delay was

instituted to catch up with the countdown procedures. Lox tanking began at 8:30 a.m. e.s.t. Lox pump problems caused a 25-minute delay in the count. A 2-minute hold at T−6.5 minutes was requested by Mercury Control. The count then proceeded normally to T−0. Lift-off of 109D and Astronaut Glenn occurred at 9:47 a.m. e.s.t. Propulsion system operation during ignition was satisfactory. The longitudinal oscillation normally expected at lift-off were nominal and damped out by approximately 25 seconds after lift-off. Performance of the guidance system was satisfactory. The missile was acquired by radar at the normal time, and tracking was maintained continuously throughout SECO. Steering began at 155 seconds with 60-percent pitchup and 23-percent yaw right commands of 10 and 5 seconds duration, respectively. These initial commands were acceptable for the planned trajectory. Thereafter pitch steering did not exceed 10 percent and yaw steering 5 percent until the end of the flight. Flight control system performance was satisfactory. All monitored programer pitch functions occurred at the proper time. Staging sequence was normal and no evidence of pitch oscillation buildup occurred during the flight. Insertion accuracies were good and well within the tolerance requirements established by NASA. Postflight evaluation of the mission indicated that all systems functioned satisfactorily, and no significant anomalies were apparent.

### MA–7

Atlas 107D was shipped to AMR on March 7, 1962, to support the MA–7 flight of Astronaut Carpenter in spacecraft number 18. The vehicle was erected on March 14, 1962, and no serious problems were found during the prelaunch activity. A joint spacecraft and launch-vehicle flight-acceptance composite test (FACT) was conducted on May 4, 1962. The Flight Safety Review Board met on May 23 under the chairmanship of Lt. General Estes, then Commander of SSD, for the purpose of determining the readiness of 107D to support the second Mercury manned orbital launch. The combined Atlas-Mercury countdown began at T−390 minutes at 11:00 p.m. e.s.t. May 23, 1962. The count proceeded very smoothly and without delay until T−11 minutes when the NASA flight director called a 15-minute hold because of unfavorable ground visual conditions. An additional 15-minute hold for the same reason was requested. At 7:17 a.m. e.s.t. an additional 10-minute hold was requested to analyze airborne refractometer test data to determine its effect on the ground guidance system. At 6:28 a.m. e.s.t. an additional 5-minute hold was called to complete the analysis of the refractometer data. Countdown was resumed at 7:34 a.m. e.s.t. and proceeded normally to T−0.

The Atlas vernier-sustainer and booster ignition and transition to mainstage were normal. Lift-off transients were very small and the normal pitch oscillation seen during the roll program was of minimum magnitude. Guidance lock-on was normal. No yaw command was necessary at the time of guidance enable. A slight pitchup was commanded, after which no steering commands were required until just before SECO. Staging transients were very small. An anomaly occurred in the sustainer hydraulic system when at T+192 seconds telemetry data showed that the sustainer engine control hydraulic pressure had begun to drop. The number two ASIS pressure switch activated at T+265.1 seconds when system pressure dropped below the abort level. The number one ASIS switch, which is on a separate sensing line, did not activate and therefore no abort signal was generated. Other telemetry measurements did not show corresponding hydraulic pressure drop. Test simulations conducted after the flight duplicated flight test indications when the sense line was cold soaked at liquid oxygen temperatures. Action was taken to modify future Mercury vehicles by insulating the sense lines. Guidance accuracies for the flight were improved as a result of the extension of the ground based rate system base legs. This was the first Mercury flight to incorporate this modification.

### MA–8

Atlas launch vehicle 113D scheduled to support the MA–8 mission on October 3, 1962, incorporated the baffled injector modification in the two booster engines. Sufficient ground and flight test experience had been conducted to provide adequate assurance of the additional flight safety possible with this modification. However, recent ground and flight test failures of

the sustainer turbopump created a new atmosphere of concern in the engine area. Investigation of these failures did not reveal any specific cause. Therefore, additional testing was required to determine the susceptibility of 113D to a similar malfunction. An extensive analysis of these past failures did point out that two conditions were common to the failures. The first condition was that the failure occurred during the period of time the fuel control valve was moving into the control position during start. Secondly, the malfunction had always occurred during the initial test of the system in that configuration. For these reasons it was determined that conducting an FRF on 113D in its launch configuration should expose the turbopump to this failure mechanism. Accordingly, an FRF was conducted on September 8. Post FRF evaluation indicated that the propulsion system was flight ready.

Major General Ben I. Funk, Commander, SSD, conducted the Flight Safety Review for the MA–8 mission at 9:30 a.m. e.s.t. on October 2, 1962, to determine the flight readiness of Atlas 113D. NASA concurred with the board's recommendation that the vehicle was in suitable condition to support the MA–8 mission.

MA–8 (Atlas 113D) was launched at AMR Complex 14, 7:15 a.m. e.s.t. on October 3, 1962. The performance of the propulsion system was satisfactory. Telemetered values of all measurements were indicative of normal system operation. Because of the incorporation of the production baffled thrust chamber injectors on the booster engines the missile hold-down time was not extended, and the rough combustion cut-off system was installed open loop on the booster and the sustainer engine for instrumentation purposes only. Flight control data indicated the usual clockwise roll transient at lift-off; however, in this case the transient condition approached 80 percent of the abort threshold. Longitudinal oscillations and pitch oscillations during the initial portion of the flight were nominal and slosh amplitudes were within expected values. All monitored programer switch functions occurred at the proper times and staging sequence was normal. A low amplitude roll limit cycle was apparent from approximately 252 seconds to SECO. Performance of the guidance system was satisfactory with negligible steering commands required after responding to the initial inputs. Insertion conditions were very close to nominal.

### MA–9

Atlas 130D was the sixth consecutive launch vehicle to place a Mercury spacecraft into earth orbit. It was the tenth and final launch vehicle used in the Mercury-Atlas program. 130D was accepted at the General Dynamics/Astronautics plant at San Diego, California, on March 15, 1962. Acceptance of this vehicle marked the attainment of a long standing goal of the SSD–Aerospace launch vehicle program offices: acceptance of a Mercury-Atlas launch vehicle without discrepancies or contractual deviations.

The Flight Safety Review Board convened on May 13, 1963, with Major General Ben I. Funk, Commander, SSD, as chairman, to review the status of Atlas 130D to support the MA–9 mission. The MA–8 launch-vehicle performance and the MA–9 launch-vehicle predicted performance were reviewed. All differences between the MA–8 and MA–9 vehicles were discussed, as well as the flight qualification of these changes. The history of manufacturing and testing of 130D at the manufacturer's plant and the prelaunch history at AMR were reviewed. Atlas flight-test experiences were updated to insure that no related problems existed and the board agreed that 130D was ready for flight. An initial launch attempt was made on May 14, 1963; however, the diesel engine used for retracting and stowing the gantry caused a delay in the count when it malfunctioned. Subsequently, the launch was postponed until the following day because of a malfunction in the radar at Bermuda.

The Atlas prelaunch operation, which began on time at midnight of May 14, 1963, was scheduled for a 390-minute countdown plus one planned hold of 90 minutes duration at T—140. There was one unscheduled hold of 4 minutes duration at T—11 minutes 30 seconds, to investigate a signal fluctuation in the Mod III ground guidance system. The anomaly was attributed to an outside source of radiation, and the countdown was resumed. The whole launch vehicle countdown had been exceptionally smooth, and no further delays were encountered. Ignition, transition to mainstage and lift-off were normal with no additional

hold-down beyond the normal approximately 2 seconds between flight lock-in and release. Lift-off occurred at 8:04:13 a.m. e.s.t., on May 15, 1963. As the vehicle came off the launcher arms it rolled counterclockwise approximately 0.3° before this minor transient was corrected by autopilot control initiation at 40″ motion. The expected slight longitudinal oscillation associated with lift-off occurred during the first few seconds of missile motion and damped normally. At two seconds after lift-off the roll program was enabled and 130D rolled toward its climbout heading of 72°. The roll program was completed at 15 seconds, and the booster pitch program was enabled. Slight lofting took place during the early portion of the booster powered flight; however, the vehicle intercepted the planned trajectory at 125 seconds. Propellant sloshing became noticeable at 55 seconds, reaching a maximum amplitude at 98 seconds and decaying to a negligible value by 120 seconds. Propellant slosh during this period of time is normal, but the amplitudes on this flight were higher than on most previous Mercury launches. Postflight review of the 130D flight control gains indicated they were within tolerance but below nominal. Higher than normal propellant slosh amplitudes could be expected under these conditions. Booster engine cut-off (BECO) was accomplished at 132.5 seconds with booster section staging at 135.4 seconds. Space position at BECO was very close to planned. At BECO the sustainer engine was nulled in pitch and yaw to assure proper clearance of the booster section during the jettison phase. After booster jettison the sustainer was reactivated in pitch and yaw. The sustainer-stage pitch program was initiated at staging plus 5 seconds and was completed at 159 seconds after lift-off. Entrance into the guidance steering mode was relatively smooth with the initial steering response being slightly up and to the right. After the initial correction, only extremely small steering commands were transmitted. SECO occurred at 303.03 seconds, approximately 1 second earlier than planned. Burnout conditions of the launch vehicle were very close to those planned and were within a few feet per second high in velocity, 500 feet low in altitude, and 0.005° low in flight path angle.

A detailed analysis of flight test data has shown that the launch vehicle performance was very close to nominal. An over-all vehicle postflight trajectory simulation did indicate that the effective specific impulse of the total launch vehicle system was within, but on the high side, of the tolerance band.

The pneumatic system operated satisfactorily, and no anomalies were noted. The tank pressure oscillation which normally occurs at lift-off was of very low magnitude and of no significance to the flight. Adequate pressures were maintained in both lox and fuel tanks and well above the abort limits at all times.

The propellant utilization system exhibited very smooth characteristics throughout the flight and was holding at the nominal position during the period prior to sustainer engine cut-off, indicating that the propellant mass ratio was correct. The PU system on this flight utilized a slightly reshaped mandrel and improved calibration techniques compared to previous Mercury flights.

The sustainer and booster engine hydraulic systems behaved in a normal manner with only slight booster position response to auto-pilot system demands occurring during the propellant sloshing period.

The a-c power supply frequency and the main battery voltage were within specified limits through powered flight. The a-c voltage ran 0.4 to 0.7 volt above the nominal but within the tolerance band. Slight vehicle lofting occurred as a result of this minor shift in a-c voltage.

The flight control system functioned satisfactorily and properly stabilized the launch vehicle. All guidance discrete and steering command functions of the flight control system were properly carried out. GE and Azusa data indicated that the total magnitudes of the booster phase roll and pitch programs were extended slightly beyond nominal but were still well within allowable limits. The major contributor to these excesses was the higher than normal inverter voltage output during the launch to BECO phase of powered flight. It should be noted that the effect of higher than nominal engine performance during boost phase tended to counteract the effect of higher than nominal

inverter voltage on the pitch program. As previously pointed out, the propellant slosh was greater than that on most previous flights but its effect on attitude rates was negligible. A low-amplitude roll limit cycle was evident from BECO to SECO. This motion had been noted on previous Mercury-Atlas flights and was not considered detrimental to the mission.

All instrumentation measurements functioned properly throughout the flight, and the telemetry quality was such that a very thorough analysis of all flight parameters was possible.

The range safety command system was not required until the auxiliary sustainer cut-off signal (ASCO) was transmitted 0.04 second after the BECO guidance discrete signal in accordance with the computer program logic.

Performance of the ASIS was satisfactory. Review of launch-vehicle data did not reveal the existence of any undetected abort condition. Switching functions to change abort logic and parameter levels were accomplished in the planned manner from launch throughout powered flight to SECO.

# 6. RELIABILITY AND FLIGHT SAFETY

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**Summary**

This paper summarizes the reliability and flight safety features of the Mercury Project. The difference between reliability and flight safety is briefly discussed. The basic concept that no single failure would cause an abort, and that no single failure during an abort would result in loss of the pilot, dictated the need for redundancy and manual over-ride capabilities in spacecraft critical systems.

An existing missile was modified to provide the launch vehicle, and its reliability was augmented by a program of special testing and by careful selection of components. In addition, an abort sensing system was developed for the launch vehicle to provide for sensing of impending catastrophic failure and activation of the spacecraft escape system.

A conservative design approach was used for the spacecraft, incorporating redundancy in all critical systems where possible, in order to provide reliability. Off-the-shelf proven components were used where possible to avoid development problems, and standard design practices were used for designing components where proven components were not available.

The success of the flight-test program proved the effectiveness of the ground test program in disclosing essentially all "early development" and human induced type failures.

Flight safety reviews for the launch vehicle and the spacecraft, and a mission review for all aspects of the mission, were conducted prior to each mission and proved to be effective.

## Introduction

The Mercury approach to reliability and flight safety was a practical approach to the problem of achieving manned orbital operation with a reasonable degree of reliability and safety at the earliest possible time. It was an all-out effort to apply knowledge and experience accumulated in years of aircraft and missile flight to get the best chance of mission success and flight safety from parts and components that already existed, or would be brought to the flight stage in, roughly, 2 years. The success of manned space flight required an extensive effort involving dedication of many individuals and their unstinting use of time, there being no sophisticated shortcuts to the disclosure of the many problems and the solving of these problems to assure success of each flight. Consideration of cost, manpower, or schedule were never allowed to influence any decisions involving mission success or flight safety.

Throughout the program, there proved to be a need for stringent attention to details of design, fabrication, quality control, testing and training; emphasis was placed on streamlining the failure analysis and corrective action procedures, incorporating on-the-spot failure analysis at the launch site.

Reliability and flight safety, although closely related, are not exactly the same thing. The former refers to the probability that a given mission will proceed to completion without mishap. This probability combined with the reliability of the escape system provides the overall flight safety or probability of crew survival. It may be pointed out that flight safety can be achieved by building a high reliability vehicle with little or no provisions for escape, as in the case of a commercial airliner, or by attaching a highly reliable escape system to an unreliable vehicle.

Two key design philosophies or guidelines can be postulated:

(1) No single failure shall cause an abort.

(2) No single failure during an abort will result in the loss of life of the crew.

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Obviously certain items fall outside the scope of these rules. These are such passive subsystems as the ablation shield and the spacecraft structure as well as some large active elements having a background of high reliability such as the launch escape rocket.

What might be termed the Mercury approach to mission accomplishment and crew safety is outlined in the figures accompanying this report. It may be described conveniently under three main headings, the launch vehicle, the spacecraft and the operational procedures and philosophy.

The success of the mission and safety of the crew also depended on a number of other considerations such as the efficiency of the worldwide network of communications and the recovery operations, both of which are discussed in other papers.

## Launch Vehicle

The launch-vehicle reliability and flight safety features are shown in figure 6–1. The main features indicated here are the use of an existing missile modified for Mercury requirements and augmented by a special pilot safety program and an abort sensing system. Although the following discussion centers around the Mercury-Atlas program, similar procedures were put into effect for the Mercury-Redstone program.

### Existing Missile

The Atlas and Redstone missiles were chosen as launch vehicles because they were already far along in their development phases and would thus require only minor modification to adapt them to the Mercury requirements. This choice had a number of important implications as to reliability and crew safety, some favorable and some unfavorable. On the credit side, the particular vehicles chosen were well along on their development cycles, had considerable flight experience behind them, and had already demonstrated their abilities to meet the performance requirements. Another favorable feature of the Atlas launch vehicle was the fact that all engines were started, and satisfactory engine operation was verified, before lift-off.

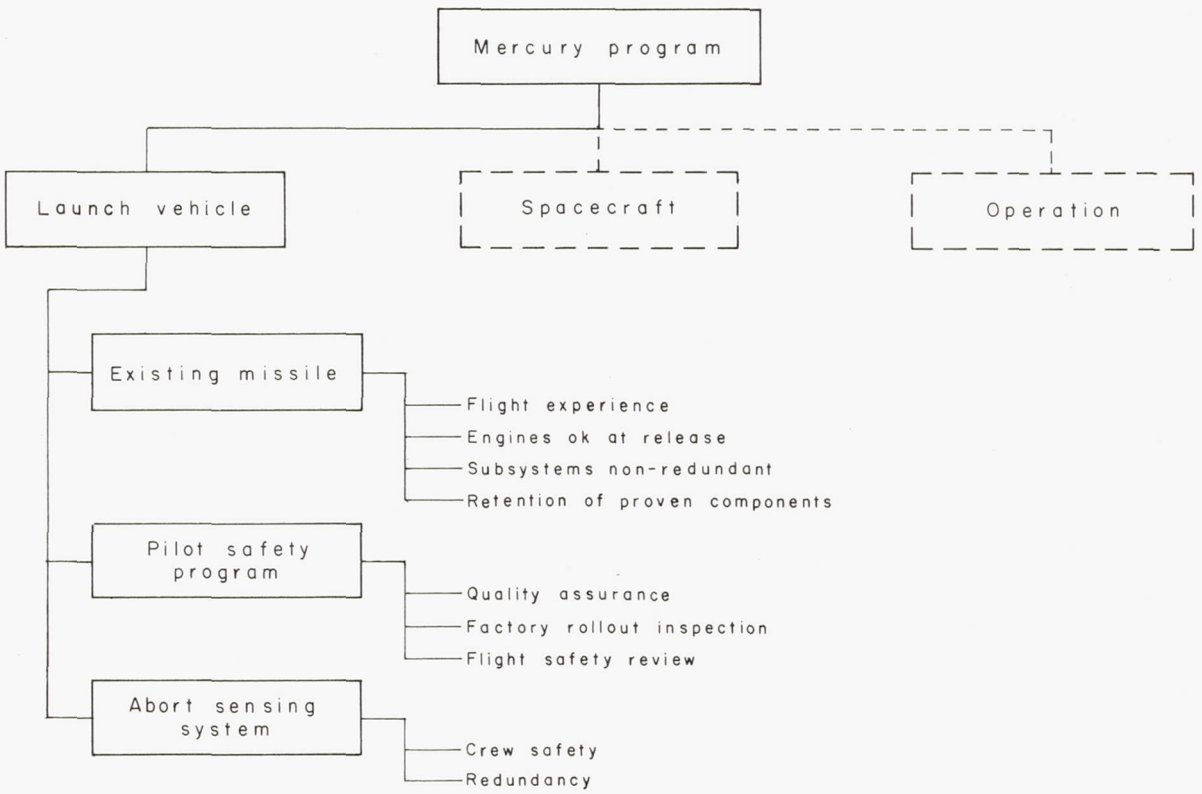



FIGURE 6–1.—Launch vehicle reliability and flight safety features.

Since the Mercury-Atlas vehicle was used as the launch vehicle for the orbital missions, the following discussion will be centered around this vehicle.

A determined effort was made to retain the proven components on the launch vehicle since the development of new components would have resulted in the loss of much of the advantage of using a developed launch vehicle.

### Pilot Safety Program

The Pilot Safety Program (see fig. 6–1 and 6–2) was added in the Mercury Project to augment the reliability and safety of the basic Atlas system. This program was developed by the Air Force for the selection and preparation of the Atlas launch vehicles for manned Mercury flights. It was recognized that major design changes to increase the reliability potential of the basic design could not be accomplished within the life of the Mercury Project, and therefore special efforts would be necessary to make certain that the maximum reliability of which the design was capable would actually be achieved in Mercury operations. The program that resulted involved three parts, a Quality Assurance Program, a Factory Rollout Inspection Program, and a Flight Safety Review Program at the launch site.

The Quality Assurance Program consisted of two major areas: An educational program for contractor and sub-contractor personnel; and a critical parts selection program.

Training conducted by the contractor created an awareness of the importance of the Man-in-Space Program and the high reliability required of the Mercury-Atlas launch vehicle. High quality through careful workmanship was stressed.

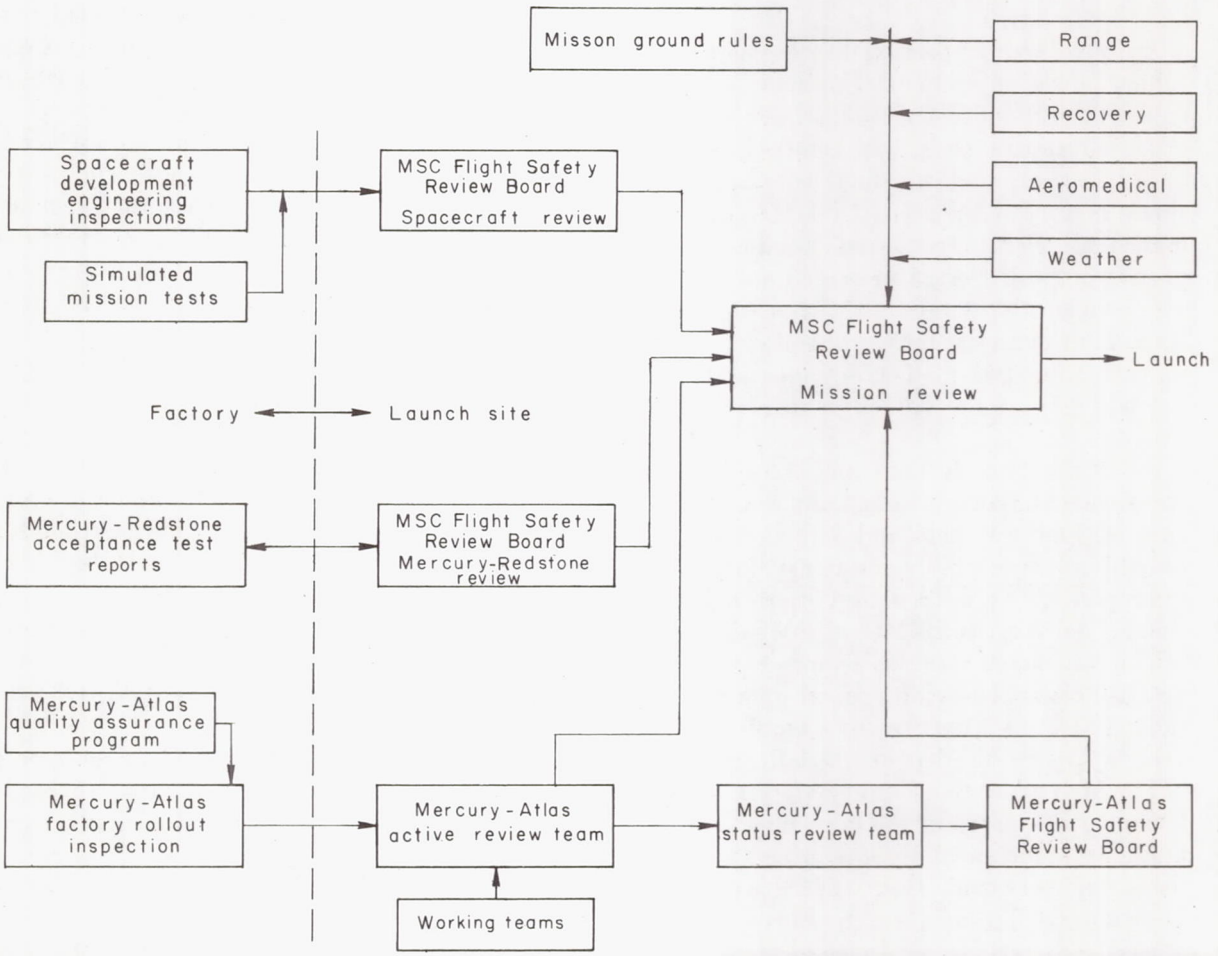



FIGURE 6–2.—Mission review activities.

The result of the critical parts selection program was the rejection of components and subsystems with excessive operating times, on nonstandard performance, or questionable inspection records. Choice of Mercury-Atlas launch-vehicle engines was limited to those standard Atlas engines whose performance parameters most closely met the exact specification requirements. Spare parts were also selected with the same care given to flight hardware. All selected units were specifically identified as accepted Mercury hardware and stored in a specially designated and controlled area.

The Factory Roll-Out Inspection assured that the Mercury-Atlas launch vehicle was complete, functionally acceptable, and ready for delivery. The technical roll-out inspection team consisted of specialists in the technical areas of each flight system. General launch vehicle progress was analyzed on a continuing basis, with special emphasis on hardware status and replacements.

A pre-roll-out inspection meeting determined vehicle status and potential problem areas. A tentative roll-out inspection schedule was established at this time, and composite test go-ahead was granted for final contractual Air Force factory acceptance of the Mercury-Atlas launch vehicle. After satisfactory completion of the composite test, a pre-acceptance meeting was held by the Air Force with associate contractors prior to the formal acceptance meeting to determine systems-performance status and acceptability of the launch vehicle to the Air Force.

After the final Rollout and Acceptance Inspection at the contractor's plant, a post-acceptance critique was held and a final report prepared to cover assembly and test history and all discrepancies uncovered and corrected up to time of delivery to the Atlantic Missile Range.

The contractor was also required to submit a detailed report covering critical item qualification status. A functionally complete launch vehicle was required prior to delivery.

The Mercury-Atlas Flight Safety Review determined the status of the launch vehicle flight readiness. Technical flight readiness was established by personnel from the Space Systems Division (SSD) of the Air Force and their associate contractors who met prior to planned launch for complete vehicle history review since arrival at AMR. The team determined that all possible efforts to insure a successful mission had been made and that the vehicle was in a state of technical readiness. Complete review of all facts yielded a "go" or "no-go" recommendation to the Mercury-Atlas Flight Safety Review Board, which was chaired by the Commander, SSD, for the manned orbital flights. This Review Board meeting was attended by NASA observers, including the NASA Operations Director and one of the astronauts. The findings of this board were subsequently conveyed officially to the NASA Operations Director in the Mission Review.

The total scope of the Pilot Safety Program resulted in expenditure of about twice the standard Atlas fabrication time, and more than three times the normal checkout time and attention.

#### Abort Sensing and Implementation System (ASIS)

The abort sensing and implementation system (ASIS) was conceived and developed to enhance crew safety. The functions of this ASIS were to sense impending catastrophic launch-vehicle failure, automatically generate an abort command, and activate the spacecraft escape system in sufficient time to assure astronaut safety. An abort signal would be generated if pre-selected tolerances of certain critical launch-vehicle performance parameters were exceeded. The ASIS was supplemented by manned ground and spacecraft abort capabilities.

Atlas flight test data were analyzed to determine which specific performance parameters should be monitored and to determine the abort threshold levels, to assure that sufficient time for escape would be provided and that false abort commands would not be generated.

Evaluation of ASIS reliability under extreme environmental conditions was carried out by an extensive ground-test and flight-test program.

ASIS reliability was provided by electronic equipment redundancies designed to preclude the possibility of system failures or inadvertent aborts. There were deficiencies in the ASIS discovered during the development flights, but corrections were made prior to use on the Mercury-Atlas flights. Early unmanned Mercury flights proved out the entire system; successful abort was initiated on the MA–3 flight, saving

the spacecraft which was flown again on MA–4. There were no manned Mercury flights which required an abort action by the ASIS, nor were there any false ASIS abort signals.

ASIS was supplemented by the following manned abort capabilities:

(1) Off-the-pad aborts could be initiated by the test conductor, through direct electrical circuitry, until the vehicle had lifted 2 inches from the pad.

(2) From the point of 2-inch vertical ascent through the end of powered flight, an abort could be initiated through the Mercury Control Center (MCC) radio-frequency link.

(3) The mission could be terminated at any time throughout the entire powered flight by the astronaut.

(4) Indirect abort capability was provided the Range Safety Officer. The automatic airborne abort system could be activated by supplying a manual engine cut-off command. A 3-second airborne time delay was integrated with the airborne range safety command receiver to insure a safe separation of the spacecraft in the event that a command destruct signal became necessary.

### Spacecraft

The size, complexity, and cost of the spacecraft and related operational activities including recovery precluded a program of using general flight testing to uncover design and systems weaknesses. It was necessary to produce the first and following spacecrafts with sufficient reliability to assure that each flight would complete its mission. The following discussion covers the reliability and flight safety features of the effort expended in Mercury to accomplish this result. The features are shown on figure 6–3 and may be described under the four head-

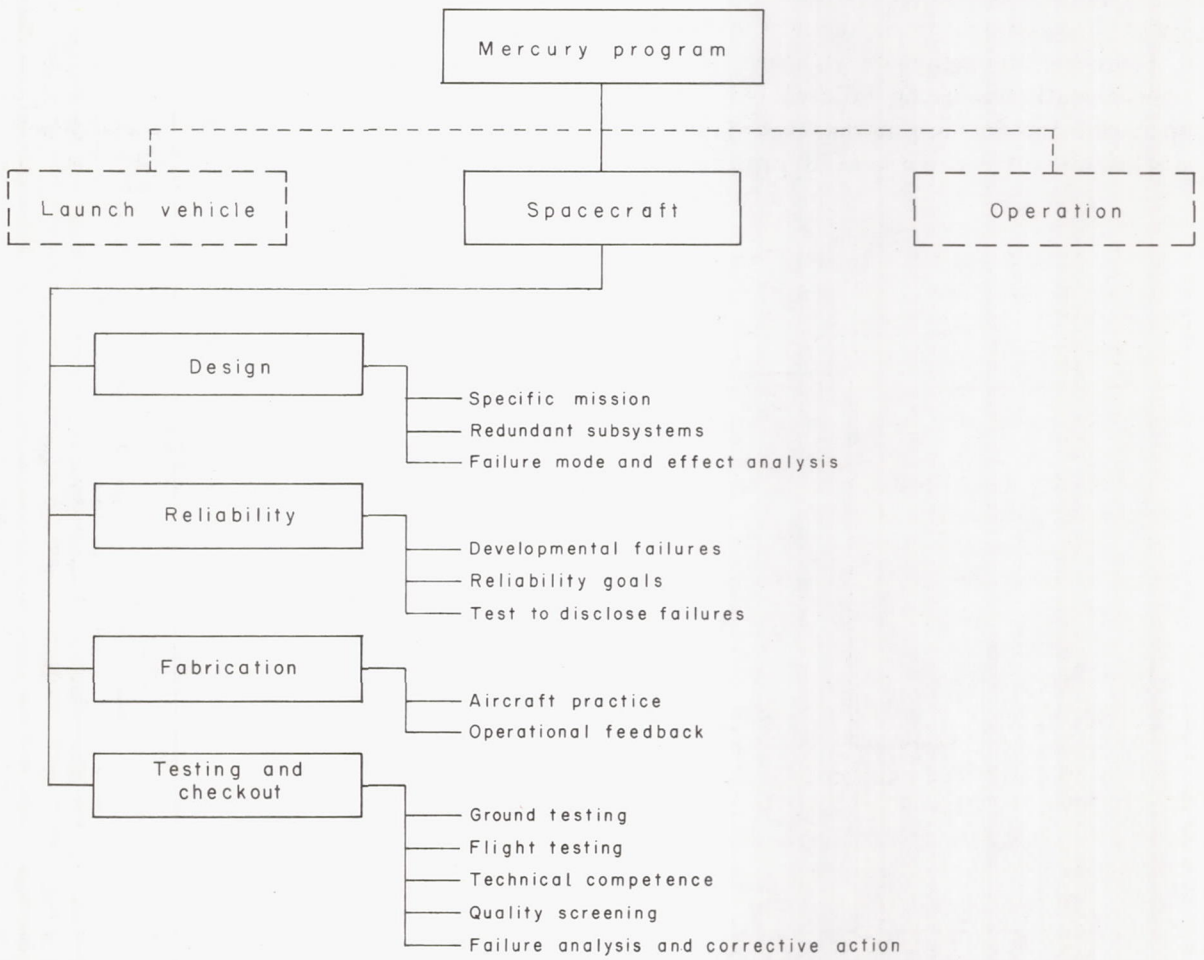



FIGURE 6–3.—Spacecraft reliability and flight safety features.

ings of design, reliability, fabrication, and testing and checkout.

### Design

The spacecraft was designed specifically for manned orbital flight with virtually no background of applicable experience to serve as a guide. A very conservative design approach was adopted to provide redundancy in all critical subsystems where possible. The original design was required to provide for normal manned operation, unmanned operation, and operation with an incapacitated man aboard. Much of the redundancy, particularly in the smaller items such as explosive bolts, igniters, etc., was functional in both the unmanned and manned vehicles, but for manned flights the major subsystems such as the attitude control system and landing system relied on pilot operation of the backup mode: hence, the presence of the pilot substantially increased the reliability of the spacecraft in the manned missions.

There was an average of ten spacecraft component malfunctions or failures per manned spacecraft mission despite the level of effort to disclose and correct all anomalies prior to flight. However, in no case did these failures, some of which were critical, result in mission failure. The adopted design approach utilizing equipment redundancy and pilot back-up modes proved its effectiveness.

Insofar as reliablity and safety were concerned, components selected or fabricated for use in the subsystem were representative of the state-of-the-art at the time of the design freeze. Standard design practices were utilized for designing components for specific applications where proven components were not available.

The philosophy of designing redundancy into Project Mercury is best described by the following examples:

*One-time-only operating devices.*—A number of subsystems are required to operate only once during a mission, and thus the frequency of failure of these subsystems is independent of mission duration.

In order to be sure that the escape tower could be released from the spacecraft, and that the spacecraft could be released from the launch vehicle, the clamp rings were divided into three segments and held together by three double-ended explosive bolts. Figure 6–4 shows the

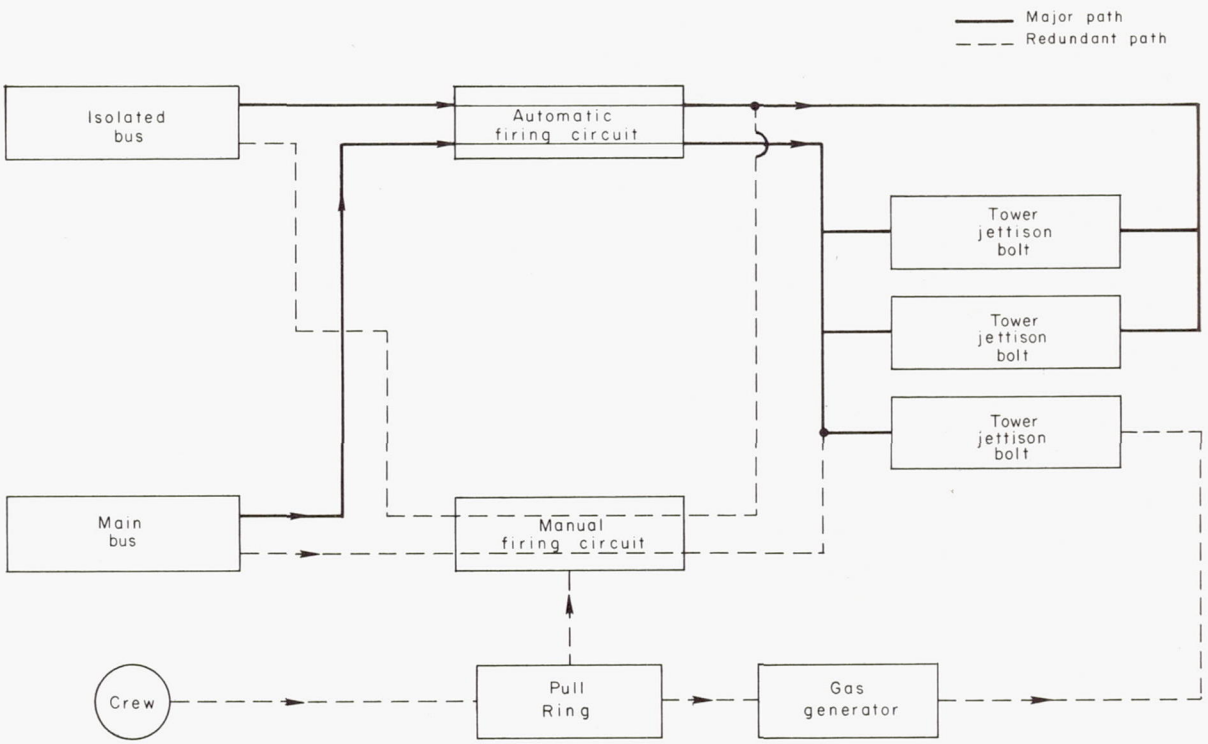



FIGURE 6–4.—Automatic and manual initiation of tower-jettisoning-bolt, pyrotechnics.

escape-tower clamp ring bolt-firing functional arrangement. Firing any end of any bolt could effect the release. The automatic system could fire one end of each bolt from one electric circuit and the opposite end of two bolts from a completely independent circuit; an astronaut manually operated backup could fire the opposite end of the third bolt through a percussion device, and in addition, could send electrical signals through the two automatic electric circuits.

For retroimpulse there were three solid fuel rockets with dual igniters fired by dual circuits. They could be initiated automatically, or by either astronaut or ground command. Only two of the three retrorockets were required to effect a satisfactory reentry.

The primary parachute system was fully automatic. It incorporated dual barostats, dual power sources, and manual backup of each main function in the sequence. The entire automatic system was backed up by an independent manually operated reserve parachute system.

*Operating-time dependent systems.*—A number of critical systems of the spacecraft had to operate more or less continuously throughout the flight. The frequency of failure of components in these systems would be, in general, proportional to the length of time they were operated and hence to the length of the mission.

The environmental system incorporated the basic redundancy of a full pressure suit in a controlled cabin environment. Manual controls were provided to back up the automatic control functions. An emergency $O_2$ supply was available to the suit as a further backup in the event of simultaneous malfunctions in both suit and cabin controls.

The attitude control system, which was particularly critical for retrofire, consisted of a primary automatic system backed up by dual independent manual subsystems, one of which was completely independent of the automatic system.

*Failure mode and effect analysis.*—A failure mode and effect analysis was performed for each subsystem to investigate the failure mode of components comprising the system and determine the significance to mission success and the corrective action to be taken. This analysis also included an evaluation to determine the action that should be taken in case the systems-performance indications displayed to the pilot and transmitted to the ground stations were in disagreement. An important consideration was the probability that the sensors and indicators may malfunction and thus incorrectly dictate the need of an abort.

A concentrated effort was made to identify single point failures; first, those which would in themselves be catastrophic or prevent subsequent operation; and second, those which would cause a premature operation.

An example of a subsystem revision resulting from this effort was the change in arrangement of the dual barostats that functioned to close the circuit to the parachute deployment sequence. Originally, the dual barostats were in parallel; a failure to the closed position of either would initiate the deployment sequence. The revision placed the barostats in series, thereby requiring both to fail closed in order to initiate premature deployment.

### Reliability

An effort was initiated in the Mercury Project to make a quantitative reliability assessment and obtain an overall estimate of mission success and flight safety based on test time and failures that took place during the ground test program. The estimate of the reliability of the Mercury spacecraft utilized mathematical models of the subsystems together with failure rate data derived from actual test experience on the system parts and components.

In general, the results were not satisfactory because the applicability of the failure rate data was always highly debatable. It was a basic ground rule of the approach to manned space flight that a failure during development and preflight tests always resulted in a corrective action designed to eliminate all possibility of repetition of that particular type of failure. Hence, past failure data never applied directly to the then-current articles.

However, methods were evolved for setting up an analytical model to describe the operation of a complex system, and the computer programing on the IBM 7090 that eliminated lengthy and complex manual quantitative analysis. Those methods appear to have direct applications for assessing mission success and crew safety during the design stages of future space programs.

Mathematical models were used to some degree in the design stages of the Mercury Project. Catalogued values of failure rates that had been established by the manufacturers or various testing agencies as being representative of the random or statistical type of failure that predominates in fully developed parts comprised the inputs to these models. Reliability values obtained in this way tended to reflect the ultimate goal: that is, the minimum failure rate that may eventually be obtained with the design.

The first Mercury space flights with new systems could not be delayed pending statistically rigorous reliability tests to assure demonstration of reliability goals. The problem was therefore to decide, by a combination of engineering judgment, common sense, experience, and intuition, just when the last serious "early development" types and human-induced types of failure had been eliminated. The early development type of failure arose from design errors, interaction effects between parts and components, unanticipated environmental effects, or errors in estimating environments. The human-induced type were those associated with faulty fabrication, quality control, failure diagnosis, handling, installation, and carelessness.

As a result of the experience in the Mercury Project the role of numerical reliability assessment in manned space programs may be summarized as follows:

(1) It is desirable to specify an overall numerical reliability goal to insure that adequate attention is directed to reliability in the design stage. This goal should be apportioned or budgeted through a mathematical model down to the various subsystems and their components. The subsystem designer should be required to show that his subsystem is capable of absorbing the expected number of random or statistical type failures of parts without serious consequences or without exceeding his reliability budget.

(2) The logic flow diagrams which show functionally the systems sequence of action were especially useful since they represented primary and critical abort paths, crew inputs, and principal events. They reflected the basic ground rules relative to choice of alternate modes of operation and aborts. From these diagrams the effect of a component failure could readily be determined.

(3) Beyond this point the usefulness of formal quantitative reliability assessment procedures is debatable: the most effective approach from here on is to concentrate on establishing a testing program and quality assurance program that will assure detection and correction on all the unproven design and induced sources of system failure before flight.

### Fabrication

Fabrication of the spacecraft was generally in accordance with the accepted aircraft production practices for small lots on the order of twenty articles. Air-conditioned clean room procedures were introduced in an effort to eliminate the introduction of contaminants or debris into components.

The results of operational experiences were fed back into the fabrication process by holding frequent Development Design Engineering Inspections (DEI). The purpose of the DEI was to assure that the Mercury spacecraft as engineered and manufactured was safe for manned flight. Emphasis was placed on attaining reliability and flight safety with existing Mercury hardware. To accomplish this objective, the DEI team was responsible for conducting suitable inspections for deficiences and initiating necessary corrective action. The DEI board was authorized to make final decisions on the acceptability of the spacecraft.

Preparatory to the DEI, the inspection team reviewed in detail engineering design, fabrication, and assembly, as well as component, system, and composite testing.

### Testing and Checkout

*Ground testing.*—In addition to the standard type of qualification and acceptance tests, the following types of tests were conducted.

Demonstration tests: Demonstration tests were made to determine reliability, wherein several samples of each major subsystem were tested under simulated operational environments and duty cycles for a total operating time considerably longer than that of a single mission. The scope of these tests is shown in figure 6–5.

| | Major subsystems | Typical test time or firings |
|---|---|---|
| 1. | Environmental control system | 1500 hrs |
| 2. | Automatic stabilization and control system | 2000 hrs |
| 3. | Reaction control system - automatic | 290 hrs |
| 4. | Reaction control system - manual | 112 hrs |
| 5. | Horizon scanner | 720 hrs |
| 6. | Landing and recovery | 38 firings |
| 7. | Rockets | 27-37 firings (ea. type) |
| 8. | Sequential system | 400 cycles |
| 9. | Communications (tranceivers, audio center, transponders, beacons, etc.) | 1000 hrs (ea. type) |
| 10. | Satellite clock | 3000 hrs |
| 11. | Bolt, expl. clamp release | 108-155 firings (ea. type) |
| 12. | Bolt, retrorocket release | 106 firings |
| 13. | Battery (3000 w, 1500 w) | 20 discharge cycles (ea. type) |
| 14. | Ejector, antenna firing | 145 firings |
| 15. | Explosive egress hatch | 67 firings |
| 16. | Inverter, static | 4000 hrs. (ea. type) |

FIGURE 6–5.—Spacecraft subsystems reliability tests.

The results of these tests were questionable since the equipment being tested did not always represent production-quality hardware. In addition, actual flight hardware was subject to conditions not contemplated in the reliability testing such as handling and shipping environments, installations in high density and crowded areas within the spacecraft adjacent to unrelated heat generating equipment, and contamination external to the subsystem as well as within the subsystem.

Safety margin tests: Safety margin tests were made wherein a number of component units were tested under progressively severe environments to determine the safety margin provided.

It was necessary for such tests as Project Orbit and subsystems tests at contractor's plant, followed by the intensive subsystems checkout at the Cape, to uncover weaknesses. These tests are discussed in the following paragraphs.

Ground test program: A continuous ground test program, using a complete spacecraft and identified as Project Orbit, was instituted at the contractor's plant about midway through Project Mercury. It became apparent early in the Mercury Project that malfunctions occurring at Cape Canaveral and in the flight made it imperative that design and fabrication weakness be disclosed as early as possible. A comprehensive test program was started in which, to the greatest degree possible, the mission was simulated in real time and included orbital heating and near-vacuum effects. Obviously zero g effects, launch time and vibration, explosive devices, launch escape rocket, tower and spacecraft separation, exposure of the ablation shield to reentry temperatures, parachute deployment, and landing could not be duplicated. However, cabin environment and operation of time dependent subsystems under normal and emergency cabin environment were closely simulated. The continuous aspect of this program conducted in an altitude chamber with all systems operating as they would in a mission not only disclosed the weaknesses but validated equipment revised as a result of the malfunctions. Consequently, the test demonstrated the performance of up-to-date configurations.

The tests were very effective in disclosing design weaknesses associated with interface problems, time dependent failures, and thermal bal-

ances involving heat sinks and heat removal. A typical example of the usefulness of Project Orbit is discussed.

A revision in the gyro design resulted when, during the operation of the autopilot under an emergency mode (decompressed cabin), a failure in the gyros caused by decreased heat dissipation under vacuum conditions was disclosed. The lubricant vaporized, and there was a breakdown in insulation windings. The problem was resolved by changing the lubricant to one having a lower vapor pressure, and by using an insulation that maintained its dielectric characteristic when subjected to high temperatures.

Spacecraft subsystems tests: Spacecraft subsystems tests at the contractor's plant were followed by extensive tests at Cape Canaveral. Altitude sensitive systems were tested in an altitude chamber at the Cape since such tests were not made at the contractor's plant for each spacecraft.

*Flight testing.*—Contributing much to the success of Project Mercury was the flight test program. Each flight of this test program was designed to qualify equipment and procedures for succeeding flights as well as ultimately for the manned orbital flights. Any malfunctions that occurred in a flight were analyzed, and corrected prior to the next flight. These early flights included (1) Beach Abort for qualifying the launch escape and landing system; (2) the Little Joe flights; (3) the Mercury–Atlas unmanned ballistic flights for qualifying the structure and ablation shield under severe reentry conditions, (4) the ballistic Mercury–Redstone unmanned, primate, and manned flights, and (5) the Mercury–Atlas unmanned and primate orbital flights.

The manned orbital flights progressed in a logical manner from a 3-orbit mission to a 22-orbit mission.

*Technical competence.*—A very important feature of the Mercury approach to flight safety was the assignment of personnel with a high level of technical competence to the performance and monitoring of all preflight tests and preparations at the launch site. Senior engineering personnel, in many cases key members of the original design team, moved to the launch site and developed the launch preparation procedures. This high level of competence also extended into the quality control and inspection areas at the launch site.

*Quality screening.*—The Mercury Project has featured extremely tight quality screening for deficiencies during all preflight checkout operations. This was accomplished by providing a system for effectively reporting unsatisfactory conditions to the contractor and to NASA management, to obtain conclusive corrective action, and to eliminate irregularities and deficiencies which adversely affect the spacecraft program. These anomalies were recorded on forms noted as Unsatisfactory Reports (UR's).

*Failure analysis and corrective action.*—The effectiveness of the contractor's failure analysis and corrective action program was evolutionary and improved considerably as the project went through its transition period from unmanned to manned flight. Later in the program, it became apparent that a streamline procedure was necessary for failure diagnosis and corrective action to assure effectivity in subsequent spacecraft. In many cases joint contractor-MSC teams analyzed a failure on-the-spot, or hand-carried the failed part to the supplier where a laboratory analysis of the failure was made.

In addition to individual failure reports on all failures, the contractor maintained an up-to-date status of all failures, submitting an IBM tabulation summary to MSC monthly. This tabulation included all unresolved failures, and was used to point out critical and recurrent problems.

## Operations

### Simulated Flights

There were several features and practices in the Mercury operation that are worth mentioning in connection with reliability and safety. A great deal of attention was given to rehearsals and simulations of complete missions prior to each flight. These simulations were made extremely realistic. They not only served to verify the feasibility of planned procedures and provide crew practice for the expected flight plan, but also included a wide range of emergencies deliberately introduced to show up areas where improved planning might be needed to eliminate all possibility of confusion or indecision.

### Interface Control

With different groups responsible for the launch vehicle and the spacecraft, there was need for very special planning and procedures to insure proper handling of interface problems. It was found necessary in the field to establish a joint inspection team charged with the responsibility for witnessing all mating and other interface activities, measuring and verifying the adequacy of all physical clearances, inspecting all structural joints and electrical connections, and assuring that no debris was left in critical areas. Adequate access ports for field inspection were found to be an absolute requirement.

Special procedures were established for maintaining and periodically distributing one and only one official interface wiring diagram, reflecting the exact current status of the wiring on the vehicle at specified dates.

### Flight Safety Reviews

The final item on figure 6–6, Flight Safety Reviews, deals with the problem of determining that the launch vehicle and spacecraft were in fact ready for launch. These activities are covered in figures 6–2 and 6–7. In Mercury, the philosophy was adopted that a launch would not take place with any unresolved difficulty. To insure this, preflight launch vehicle readiness and spacecraft readiness review meetings were set up. In these meetings, representatives from engineering, operations, flight safety, astronauts, and Cape inspection reviewed in detail with the specialists responsible for the checkout of each system, all malfunctions observed in the system, and all changes and corrections made. Two sets of contractor failure records were maintained: first, a segregation of failures from all testing into specific subsystems; second, a file of all failures associated with subsystems of a specific spacecraft. From these records, it was possible to determine any general weaknesses and to review the case histories of critical areas in any specific spacecraft. These data, together with the unsatisfactory reports (UR's) and record of anomalies occurring in the subsystems checkout recorded by MSC personnel at the Cape provided a major input in these meetings.

These detailed meetings on the major pieces of equipment were followed by a Final Mission Review meeting. This meeting provided a final

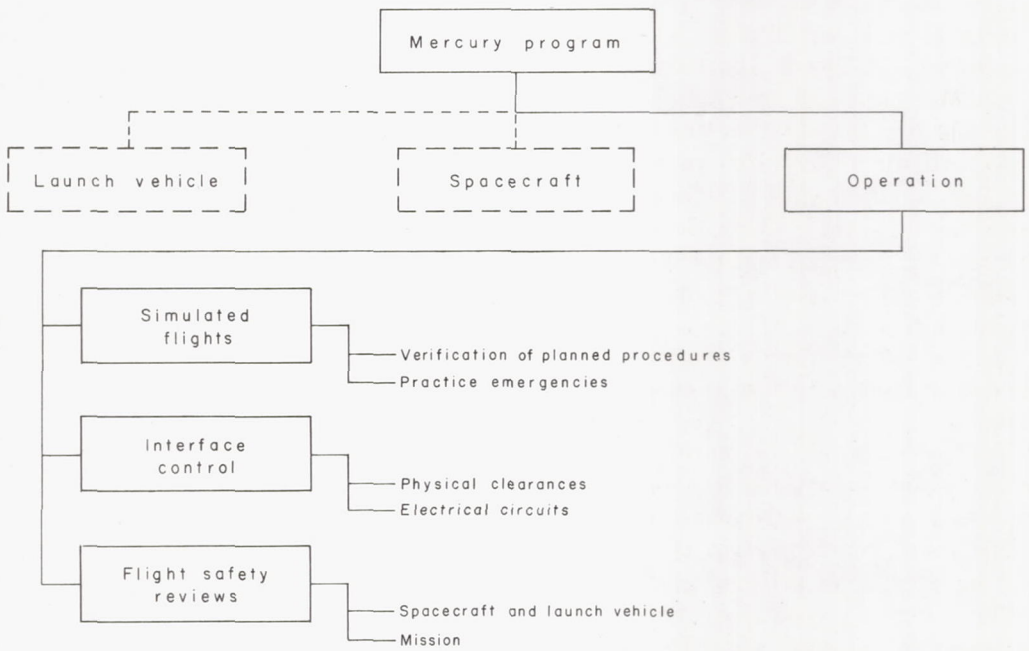



FIGURE 6–6.—Operational reliability and flight safety features.

confirmation of launch-vehicle and spacecraft readiness and established the readiness of the range, recovery, weather, and aeromedical elements.

These operating procedures were very effective in concentrating the attention of the best qualified technical talent available on the detailed engineering problems of each vehicle.

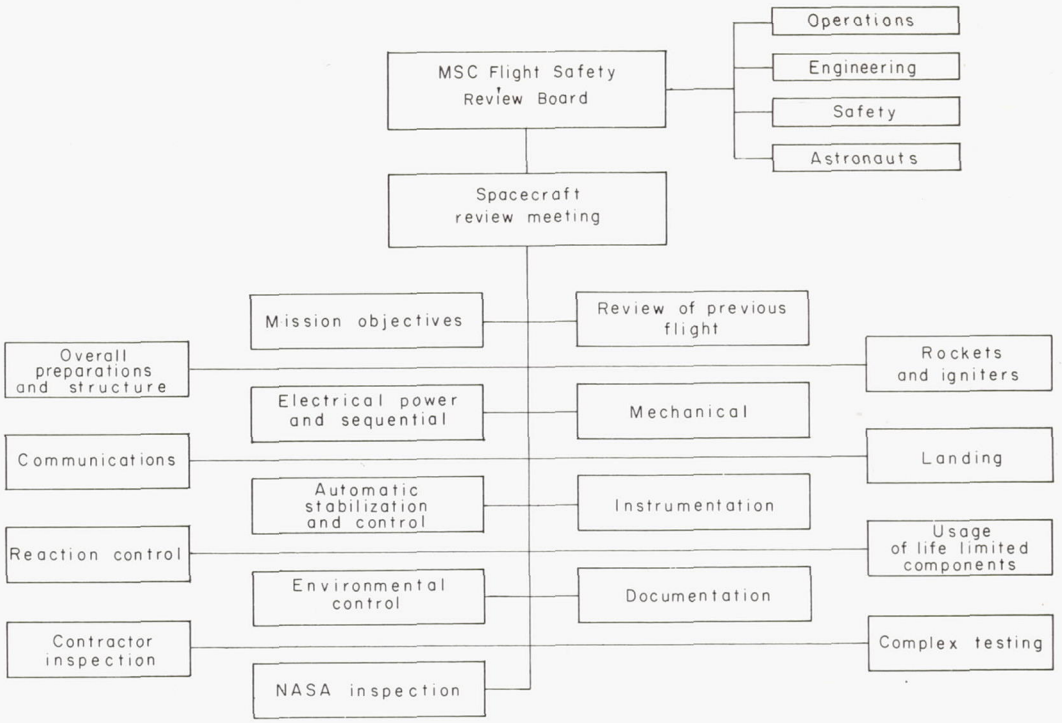



FIGURE 6–7.—Spacecraft review activities.

# II

# MISSION SUPPORT DEVELOPMENT

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# 7. TRAJECTORY ANALYSIS

By JOHN P. MAYER, *Asst. Chief for Mission Planning, Flight Operations Division, NASA Manned Spacecraft Center; and* CARL R. HUSS, *Flight Operations Division, NASA Manned Spacecraft Center*

## Summary

A description of the mission analysis studies conducted for Project Mercury is given along with specific examples for the various mission analysis phases.

Aborted mission studies constituted about 90 percent of all mission-analysis studies conducted. These studies were necessary from a flight-safety standpoint and are considered equally applicable to future manned spacecraft projects. It was found that the basic mission design must be chosen in a flexible manner so that consideration can be given to the changes in mission constraints. Real-time computing has proved extremely valuable in Project Mercury; however, consideration must be given to changes in mission operational plans which cannot be effectively included in the Real Time Computer Complex.

## Introduction

The mission-analysis effort in Project Mercury was conducted in several phases leading up to the flight missions. These phases include the mission analysis supporting the systems design of the spacecraft, the basic operational design of the Mercury missions based on mission requirements and objectives, detailed operational mission analysis for each specific flight, and the formulation of the mission logic to be included in the computer used for inflight real-time control of the missions.

## Mission Phases

In figure 7–1 are shown the important phases of mission-analysis studies. In the early mission-analysis phase, the analysis was specifically for use in spacecraft system design. For example, the maximum loads and heating conditions were determined for structural design, and the spacecraft propulsion performance requirements were determined leading to the design of the retrorocket system. After the spacecraft systems were essentially designed, the mission-analysis effort shifted to the operational phase. In this phase the system design was reasonably fixed and the detailed mission design was then accomplished by taking into account all of the constraints, including spacecraft, launch-vehicle, and operational constraints. The objective in this phase is to design a mission within the capabilities of the actual spacecraft system developed. In this phase of the mission some feedback into system design was made, although these were small changes since the early design proved to be sound.

The next mission analysis phase was in the design of specific missions. In this case the mission analysis was specialized to handle the aspects of a particular mission by using the actual performance characteristics of the launch vehicle and spacecraft being used. This phase also included the analysis for the particular operational mission objectives and ground rules developed for these missions.

The next phase was the real-time mission-analysis phase, which started at the beginning of the launch countdown and lasted until the

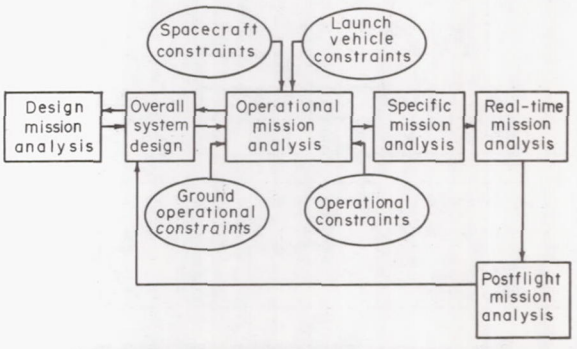



FIGURE 7–1.—Mission analysis sequence diagram.

vehicle was recovered after the mission. In this, calculations were accomplished in real time by a computer; however, the logic and equations used in this computer were developed in the preceding operational mission-analysis phase. Although every effort was made to anticipate all the possibilities that could affect the flight and include them in the real-time computer program, these possibilities were never fully established. Therefore, mission-analysis experts were used as flight controllers and also performed auxiliary computing using off-line computers other than those used in the real-time computing complex during the missions.

The next mission-analysis phase was a post-flight analysis phase in which the information obtained from actual flights was fed back into the plans for future flights and, in some cases resulted in system modifications to the spacecraft, the launch vehicle, and the ground support system.

Some specific examples of mission constraints affecting the analysis are shown in figure 7–2. Some of the spacecraft constraints that must be considered are the performance of the spacecraft propulsion system, the spacecraft control system accuracies, and other system limitations. Some of the ground complex constraints to be considered are performance (which includes the effects of the locations of command stations and command ranges) and system limitations. Constraints involving the launch vehicle which had to be considered were performance, guidance accuracies, and systems limitations. In Project Mercury the systems limitations of the launch vehicle included heating and load restraints and the guidance radar look angle constraint.

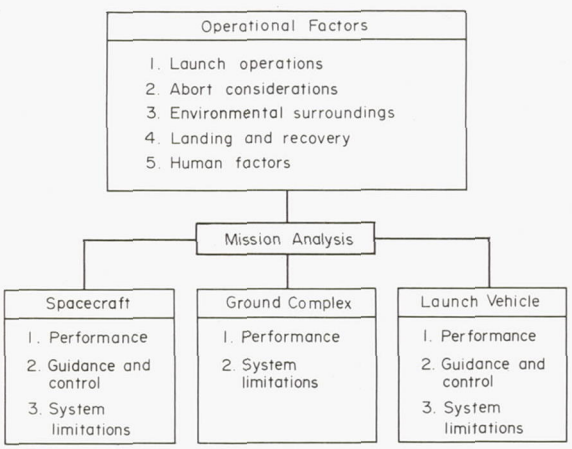



FIGURE 7–2.—Operational mission analysis.

The operational constraints to be considered in the area of launch operations are range safety limits, abort considerations, environmental considerations, landing and recovery considerations, and human factors. Some of the environmental factors that were considered were the effect of atmospheric and geophysic constraints and winds. Consideration had to be given to recovery and landing constraints for both normal and aborted missions and, in all cases, the human tolerances to acceleration loads and motions were considered.

Abort considerations resulted in about 90 percent of the mission-analysis studies. Studies were made to provide flight controllers with the information as to when to initiate aborts for maximum pilot safety. Studies were also made to determine allowable tolerances in order to obtain safe miss distances between the launch vehicle and the spacecraft and acceptable lateral loads. Also of importance were the studies to determine the abort recovery areas for all phases of the flight.

In order to illustrate some of the techniques used and the results accomplished in the mission-analysis area, a few specific examples from each phase will be discussed.

### Design Mission Analysis

One example of the work performed in the advanced mission analysis phase is illustrated by a study of the immediate post-abort conditions. The selection of the escape-rocket offset involved a compromise between high lateral loads and low miss distances between the space craft and the launch vehicle in the high-dynamic-pressure abort phase of launch. For low offset values the probability of exceeding high lateral loads was low; however, the probability of obtaining low miss distances was high. For high values of the offset the opposite is true. Thus, the selection of the offset was made on the basis of minimum combined probability of occurrence of either events. In figure 7–3 the combined probability of exceeding either a dangerous lateral load or an unacceptable miss distance is shown plotted against the escape-rocket offset.

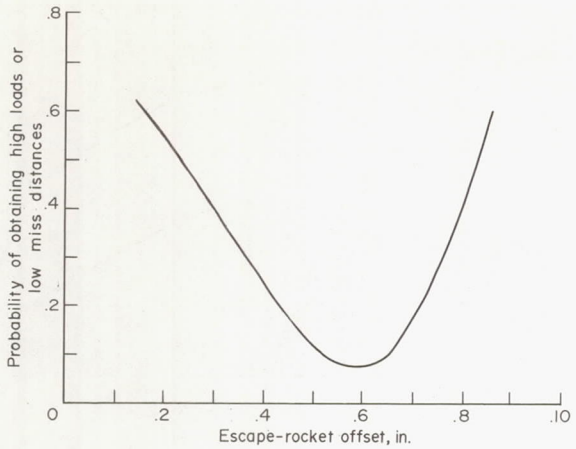



FIGURE 7–3.—Selection of escape-rocket thrust offset.

## Operational Mission Analysis

A typical example of the operational mission analysis was in the selection of the Mercury orbital elements. The orbital inclination which governed the ground track for Project Mercury was selected because the network facilities established prior to Mercury could be used to good advantage, reentries for the first three orbital passes and the 16th to the 18th passes occurred over the United States, and the orbital ground track fell within the temperate region of the world. In addition, the specific Mercury inclination was affected by launch-abort recovery considerations.

The orbital altitude and shape of the Mercury orbit were selected based on launch-vehicle performance, accuracy, and abort operational considerations. These considerations are illustrated in figures 7–4 to 7–7. In figure 7–4 the orbital lifetime is shown plotted against apogee altitude for given perigee altitudes. For Project Mercury it was desired to have minimum lifetime of 36 hours for a 24-hour mission. Since the atmospheric densities at orbital altitudes were not well-defined at the time Project Mercury was initiated, it was believed that a conservative value for density must be used for estimating lifetime. The density used in this figure is considered to be a $3\sigma$, or very conservative, dense atmosphere. From figure 7–4 it can be noted that for an adequate lifetime a circular orbit at an altitude of 105 nautical miles could have been selected, or an elliptical orbit having the same lifetime could have been selected, for example, an orbit having an 80-mile perigee and a 170-mile apogee.

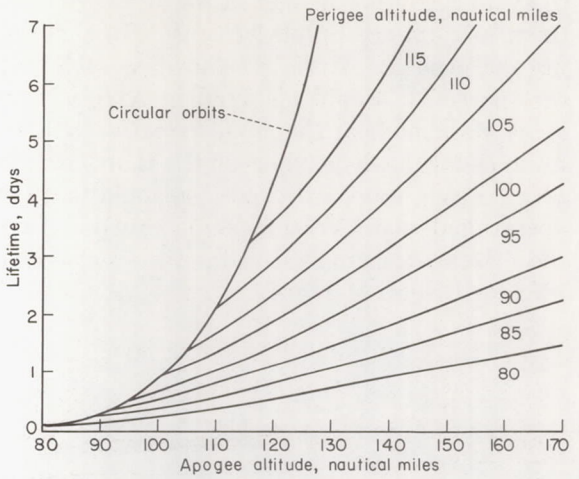



FIGURE 7–4.—Minimum lifetimes for elliptical orbits.

The next constraint to be considered is that of launch-vehicle performance. In figure 7–5 the staging time is shown plotted against the insertion or perigee altitude. The curves shown are given for a constant orbital lifetime; that is, the apogee altitude decreases as the insertion altitude increases. For a constant insertion altitude the performance, or excess velocity available above that required ($\triangle V_{min}$), increases with staging time until it reaches a peak value. For greater staging times the performance decreases. The minimum acceptable performance curves are shown in figure 7–5. The increment of velocity $\triangle V$ that defines the acceptable performance is the difference between the velocity at fuel depletion and the planned velocity. Therefore, all of the clear area in the figure would represent acceptable orbital insertion altitudes.

The launch-vehicle guidance accuracies are considered in figure 7–6. Since the Atlas launch vehicle used for the Mercury program was guided by a radio guidance system, the guidance accuracy was dependent to some extent on the radar elevation angle at cut-off. In figure 7–6 the minimum elevation angle $E_{min}$ which was considered acceptable is shown. Again the clear area in the figure is indicative of acceptable orbital insertion conditions. Next, however, the operational considerations must be included. These are shown in figure 7–7. In this

case the operational consideration which affected the orbital conditions was the requirement to avoid a landing in Africa for an abort from the minimum acceptable velocity. In this figure the position of the line shown is such that the spacecraft would not land in Africa if an abort were made at the no-go velocity, with allowance for the dispersions on the abort landing area. From figure 7–7 it may be noted that the operational consideration significantly affects the orbital insertion altitudes which could be used for Project Mercury.

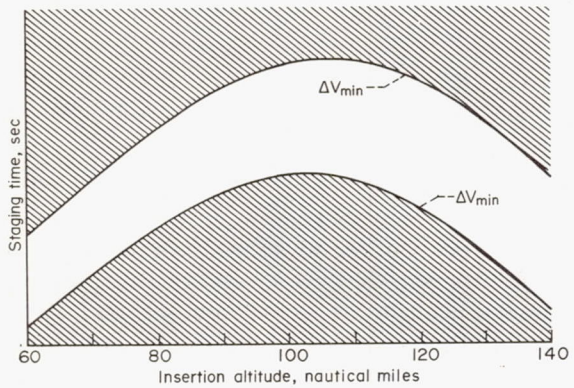



FIGURE 7–5.—Effect of launch-vehicle performance.

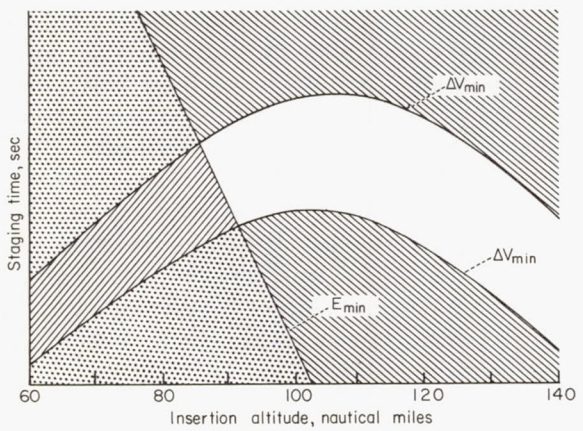



FIGURE 7–6.—Effect of launch-vehicle guidance.

As operational experience was gained in Project Mercury flights, confidence and knowledge in the systems made it possible to reduce to some extent, the original guidance and performance constraints. For example, the minimum elevation angle was reduced after obtaining a better understanding of the effects on guidance accuracy from operational experience with the guidance system.

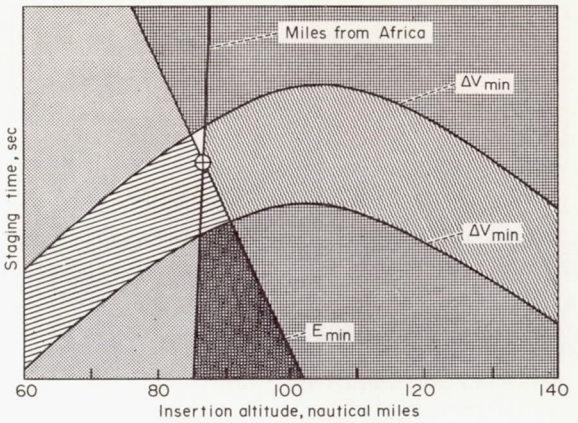



FIGURE 7–7.—Effect of operational constraints.

## Specific Mission Analysis

A considerable mission-analysis effort is made in the design of each specific Mercury flight. Included in this effort are detailed trajectory calculations for the mission, dispersion calculations, calculations concerning aborts during all phases of the mission, and calculations of retrograde time to be used in the mission. When the flight day arrived, special mission-analysis studies were performed to support the flight. These studies included evaluating the wind effects on the loads on the launch vehicle and determining the landing areas of the spacecraft in aborted missions based on actual wind profiles. In figure 7–8 the effects of the actual winds on the abort landing areas at various times of the flight are shown for the MA–9

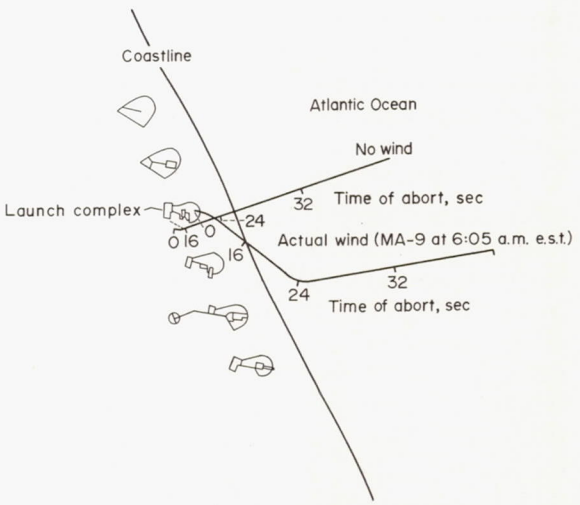



FIGURE 7–8.—Effects of actual winds on MA–9 abort landing.

mission. These calculations were made to enable the recovery forces to be positioned prior to the launch such that they could most easily make an emergency recovery should abort occur.

## Real-Time Mission Analysis

### General Computing Requirements

Real-time computing has proved very valuable in Project Mercury for use in flight control and monitoring. The basic computing requirements in real time are as follows:

(*1*) *Powered flight.*—Pertinent trajectory parameters were computed in order that the status of the launch could be monitored for any indication of an impending abort. The cut-off velocity was used to determine the acceptability of the orbital parameters based on preplanned criteria. In addition, landing points for possible aborts and radar-acquisition data were computed.

(*2*) *Aborted missions.*—For aborted missions the computer must be programed to select a target recovery area and if necessary compute the time for retrofire to land within this area.

(*3*) *Orbit.*—In this phase the orbital parameters were predicted with sufficient accuracy to establish the minimum lifetime of the orbit, to predict the retrofire time to land in normal and contingency recovery areas, to determine spacecraft orbital position, to determine acquisition data for all radar sites, and to predict the time of landing for use by recovery forces.

(*4*) *Reentry.*—During reentry the computer program recalculates and updates the landing point and time of landing, based on conditions at retrofire, in addition to predicting acquisition data for reentry radar stations.

### Example of Go—No-Go Computation

The computation of the go—no-go parameters was probably the most important of the real-time computations. The selection of the Mercury go—no-go criteria which were used in the real-time computing program is shown in figures 7–9 to 7–11. In figure 7–9 the minimum energy for an acceptable Mercury mission is illustrated. The flight-path angle at insertion is plotted against the insertion velocity. The minimum acceptable orbit was defined as that orbit in which the spacecraft could safely complete one orbital pass and land. Because of the

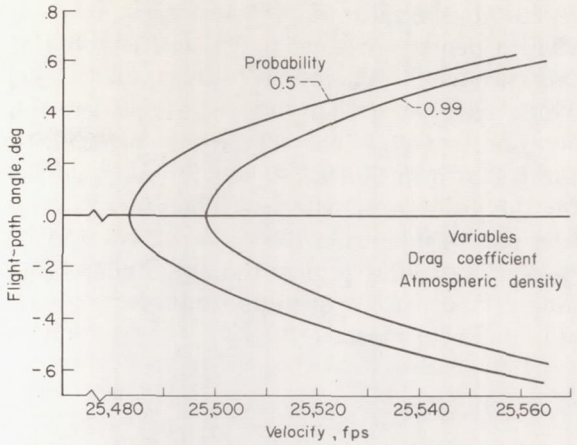



FIGURE 7–9.—Determination of minimum acceptable orbit.

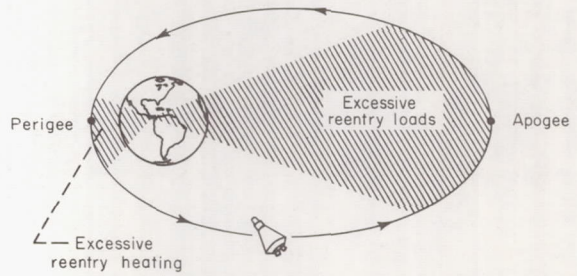



FIGURE 7–10.—Determination of maximum acceptable orbit.

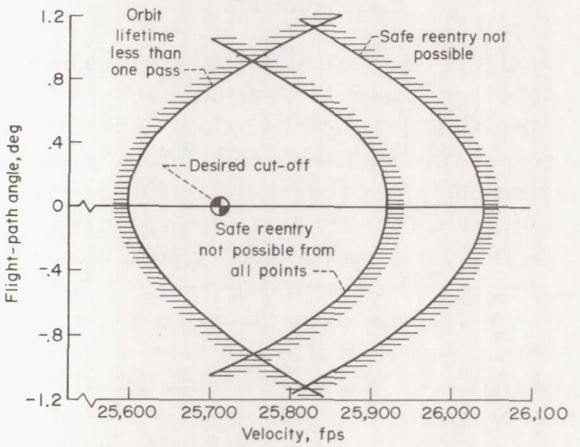



FIGURE 7–11.—Operational go—no-go orbital-insertion criteria.

critical flight safety nature of the problem, the minimum orbit was selected on the basis of a very conservative drag coefficient $C_D$ and atmospheric density $\rho$. The symbol, $(C_D\rho)_n$, shown in figure 7–12 has been normalized and

represents the ratio of the parametric drag coefficient-density product to a nominal value of this product. Therefore, values of $(C_{D\rho})_n$ which are greater than unity are considered to be conservative. The 99-percent probability curve shown in figure 7–9 was the one selected for the go—no–go criteria. Therefore from a lifetime consideration the conditions would be "go" at velocities higher than this boundary; however, other constraints imposed a limit at higher velocities.

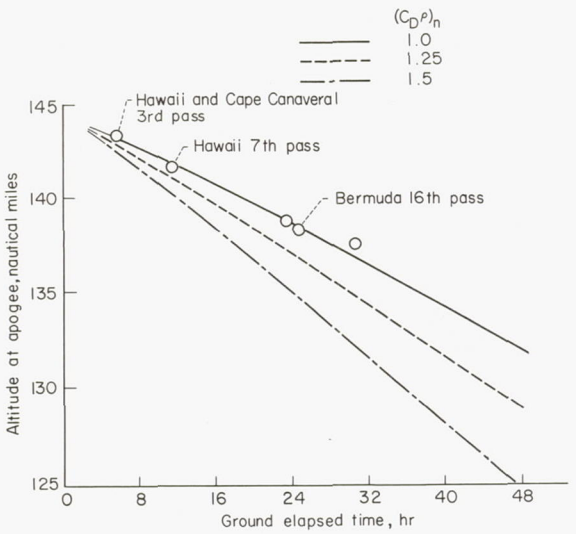



FIGURE 7–12.—Effects of actual atmosphere on MA–9 orbital lifetime.

In figure 7–10 the determination of the maximum energy orbit is illustrated. As the velocity is increased above orbital velocity the apogee increases approximately 1 mile for every 2 feet per second. When the velocity reaches a certain critical value, an area occurs near perigee such that, if the retrorockets were ignited, excessive heating would occur during reentry. As the velocity increases above this value this critical area near perigee extends over most of the orbit and another critical area for initiation of reentry appears near apogee. At this point if reentry were initiated, the reentry loads would become excessive. As the velocity is further increased, a velocity is reached in which these critical areas cover the entire orbital range and a safe reentry would not be possible from any point in the orbit. The operational go—no–go criteria that resulted from these constraints are shown in figure 7–11 where the flight-path angle at cut-off is plotted against the insertion velocity. The region for a minimum acceptable orbit lies within the boundaries shown. For all Project Mercury missions the cut-off velocities were well within the safe boundaries. For the MA–9 mission, for example, the cut-off occurred within the boundary of the symbol shown in this figure.

As was previously stated, some auxiliary computing was performed during each mission outside of the real-time computers. An example of this auxiliary computing is shown in figure 7–12 where the effects of the actual atmosphere on the orbital lifetime of the MA–9 mission are shown. In figure 7–12 apogee altitude is plotted against time. Because of the length of the MA–9 mission and the uncertainty of the density of the actual atmosphere on the day of this flight, it was thought necessary to attempt to determine the variation of the actual atmosphere from that used in preflight computations. This calculation was necessary in order to commit the mission to completing 22 passes at a predetermined time during the flight. The lines shown in the figure are for precalculated atmospheric densities which varied from that of the assumed atmosphere. The symbols in this figure indicate the actual apogee obtained during the flight and also that the actual atmosphere was very close to that used in the preflight computations. The actual orbital lifetime for the MA–9 mission would have been about 4.7 days if a reentry were not initiated using the retrorockets.

## Concluding Remarks

The operational experience obtained in mission-analysis studies for Project Mercury has proved valuable for application to other manned space-flight programs. Aborted mission studies constituted about 90 percent of all the mission-analysis studies conducted for Mercury. Although the results of these studies were not required operationally, the amount of effort spent on abort studies is necessary from a flight-safety standpoint and will be equally applicable

to future manned space projects. It is also evident that the basic mission design must be chosen in a flexible and manner so that consideration can be given to changes in the spacecraft launch vehicle or operational constraints. Real-time computing has proved extremely valuable in Project Mercury; however, it seems that consideration must always be given to changes to mission operational plans which cannot be effectively included in the real-time computing complex. Therefore, auxiliary inflight computing probably should always be considered.

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# 8. WORLDWIDE NETWORK SUPPORT

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## Summary

Because the Mercury orbital flight program required effective ground control during the unmanned and manned phases, a worldwide tracking and telemetry network was developed. Early in the project, the requirements for the network in terms of systems, installation, site locations, testing, and training for network personnel were established. Maximum utilization was made of existing facilities, but additional stations had to be implemented because of a strategic need at certain points along the orbital ground track. In addition to the telemetry and tracking facilities, two important centers were established, those of the Mercury Control Center, which was the focal point for all flight control activities, and the Computing and Communications Center. System reliability and provision for ease of maintenance were primary guidelines during the network implementation. Because of the unique spacecraft tracking task, an acquisition aid device was developed to assist in the location and tracking at first contact with the spacecraft. As the telemetry, tracking, and computation functions of the network were being installed, the network was staffed to support even the early ballistic flight program. As the scope and complexity of the missions increased, the network was expanded and modified to accept the changing and more demanding flight control and monitoring requirements. In addition to the tracking and data reception capabilities of the network, a multi-frequency air-to-ground reception and remoting provision was necessary during the manned flight program. A requirement had been established to provide continuous tracking and communications during the launch phase, as well as voice communications with the astronaut within maximum prescribed time intervals. Throughout the Mercury-Atlas orbital flight program, the Mercury Worldwide Network provided adequate and timely support in each of its charged responsibilities. Voice communications, telemetry, and tracking were satisfactory for effective flight control and monitoring, and the computation and data handling facilities provided timely support during the critical retrofire and reentry phases of each of the manned orbital flights.

## Introduction

Meeting mission objectives required that a worldwide tracking and ground instrumentation system be developed to provide a continuous flow of information to be used for mission control. The intent in this paper is to describe the evolution of the network in support of the various Mercury missions. Specifically, the paper discusses the development of network requirements and systems; installation, test, and training; the network configuration and later changes made in response to mission requirements, operations, and performance.

## Development of Network Requirements

### Approach

The task of implementing a tracking and ground instrumentation system was given to the NASA Langley Research Center (LRC). LRC formed the Tracking and Ground Instrumentation Unit to manage and direct this effort. This unit in turn utilized industrial firms to assist in determining the approach to be taken

in meeting the requirements in certain critical areas and to augment the NASA team.

### Basic Requirements

Basically, network systems were required to provide all functions necessary for ground control and monitoring of a Mercury mission from launch to landing. The function of the network was to end when the spacecraft had landed and the best possible information on the location of the landing point had been supplied to the recovery teams.

At the outset, the following functional requirements were established:

(1) Provision of adequate tracking and computing to determine launch and orbital parameters and spacecraft location for both normal and aborted missions.

(2) Voice and telemetry communications with the spacecraft with periods of interruption not to exceed 10 minutes during the early orbits, contact at least once per hour thereafter, and communications to be available for at least 4 minutes over each station.

(3) Command capability to allow ground-initiated reentry for landing in preferred recovery areas and to initiate abort during critical phases of launch and insertion.

(4) Ground communications between the ground stations and the control center.

Safety of the Mercury spacecraft and its occupant was made a dominant consideration. Speed and efficiency of installation were essential to meet the planned operational dates. Although no compromises with safety were made, economy was an important consideration in the overall plan.

### Selection of Stations

Stations were selected on considerations of the flight plan and on the character of the spacecraft electronic systems consistent with the basic requirements. Because of factors relating to the earth's rotation and the lack of suitable geographic locations, certain compromises had to be made in selecting the total number and locations of the stations required for a three-orbit mission. These compromises resulted in gaps, primarily on the third pass, greater than the desired 10 minutes. For stations selected, see figure 8–1.

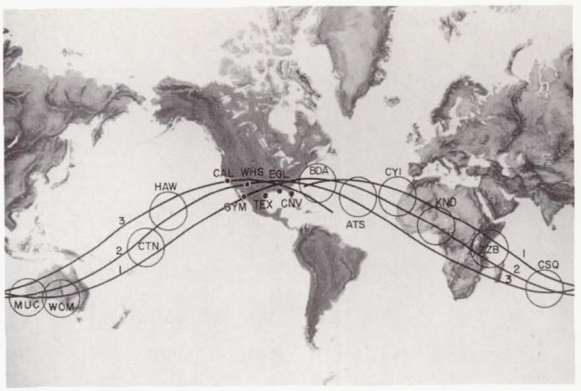



FIGURE 8–1.—Map showing the locations of the selected Mercury stations.

Two Centers were also required:

The Mercury Control Center (MCC), to be located at Cape Canaveral, was to provide equipment necessary to allow control and coordination of all activities associated with the Project Mercury operation.

The Computing and Communications Center, to be located at the Goddard Space Flight Center (GSFC), Greenbelt, Maryland, was to provide for communications control, switching and distribution; also, it was to provide all computations necessary to monitor and control the mission from launch to landing.

Such an arrangement of stations, supported by appropriate instrumentation, would provide for tracking, command, and monitoring capabilities in the highest probable abort phase of launch through insertion and for the critical reentry phase after orbital flight. It also allowed the maximum use of facilities at the National Ranges and of equipment at the Australian Department of Supply facilities at Woomera, Australia. The participating countries and ranges were as follows:

The U.S. Department of Defense provided use of facilities at the Atlantic Missile Range, Pacific Missile Range, White Sands Missile Range, and the Eglin Gulf Coast Test Range.

Australia allowed the use of certain existing facilities and construction, installation, and operations of the required new facilities. These arrangements were made through the Australian Department of Supply and were implemented by the Weapons Research Establishment.

United Kingdom permitted the construction of stations in Canton Island and Bermuda.

Nigeria agreed to the lease of land and permission to construct a station in Tungu and Chawaka.

Spain agreed to provide the land for the Canary Island station.

## Development of Equipment Systems

### Criteria and Equipment Functions

Basic equipment design and implementation criteria for this program were the result of several major considerations. One of these was economics: existing facilities were to be used wherever they met the Mercury location requirements. Thus, at six locations, a major part of the equipment, including most of the network's tracking radars, was already available. Another major consideration was time. Maximum use of existing, proven equipment was dictated by the necessity to avoid the long-lead times required for research and development. But the primary consideration, overriding all others, was the safety of the astronaut. Some of the design requirements stemming from this consideration follow:

(1) *Reliability* of components and units was required to be designed and engineered into every element of the equipment configuration, and adequate testing was required to prove this reliability.

(2) Despite rigid reliability requirements of units, *redundancy* was to be used extensively throughout each system and always at any critical point. Likewise, *diversity* was to be added to redundancy. Thus, a very reliable system was to be physically duplicated and then to be partially duplicated again by the use of an alternate frequency, location, or some other means of achieving diversity.

(3) Wherever possible, the network system should have the ability to verify its own proper functioning. Suitable monitoring and display devices were thus required.

There were also other requirements resulting from "overlapping" of two or more systems. One of these concerned interference. Determined efforts were made to minimize interference to non-Mercury users of radio frequencies; to reduce mutual interference between Mercury equipment so that there was no degradation of system performance under normal equipment operation; and, to minimize interference from non-Mercury sources by carefully selecting station locations and equipment placement. Interference studies and field measurements were to be undertaken as required. Radiated noise measurements were to be made at all sites.

Particular attention had to be given to system integration problems and to simplifications which might be possible; for example, without compromising reliability, the possibility of reducing the number of antennas at a given site by use of antenna-sharing systems had to be considered.

Finally, all equipment had to be able to withstand the environmental conditions found in such diverse climates as those of the desert at Woomera and the "salt air" of Bermuda.

To provide mission support, the equipment of the network had to provide the following major functions:

(1) Ground radar tracking of the spacecraft and transmission of the radar data to the Goddard computers

(2) Launch, orbital, and reentry computations during the flight with real-time display data being transmitted to Mercury Control Center (MCC)

(3) Real-time telemetry display data at the sites

(4) Command capability at various stations for controlling specific spacecraft functions from the ground

(5) Voice communications between the spacecraft and the ground, and maintenance of a network for voice, teletype, and radar data communications.

Development of the individual systems to meet these requirements is described in the following paragraphs. Some systems have been discussed in earlier publications (refs. 1 and 2); so they are only briefly described here, whereas other systems, especially systems requiring extensive design, are covered in more detail.

### Radar

Mission requirements dictated the need for continuous radar tracking during launch and insertion to monitor the launch phase and to establish the initial orbital parameters on which the go—no-go decision would be based. During orbital flight, additional tracking data would be required for a more precise determination of the orbital parameters and time of retrofire for the

desired landing point. As nearly continuous tracking as possible was necessary during the less predictable reentry portion of the flight to provide adequate position data on the spacecraft's landing point.

To obtain reliability in providing accurate trajectory data, the Mercury spacecraft was equipped with C-band and S-band cooperative beacons. The ground radar systems had to be compatible with the spacecraft radar beacons.

The FPS–16 radar (fig. 8–2) in use at most

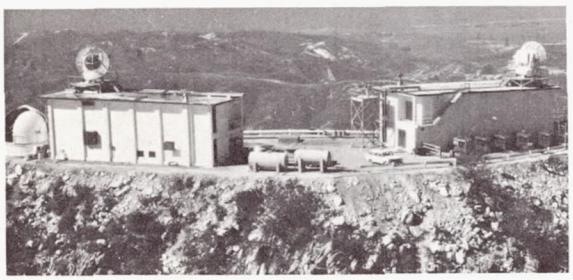


FIGURE 8–2.—FPS–16 radar installation at California.

national ranges was selected to meet the C-band requirement. Although it originally had a range capability of only 250 nautical miles, most of the FPS–16 radar units selected for the project had been modified for operation up to 500 miles, a NASA requirement, and modification kits were obtained for the remaining systems. In addition to the basic radar system, it was also necessary to provide the required data-handling equipment to allow data to be transmitted from all sites to the computers. Details on data flow and computation are discussed subsequently in the computer section.

The FPS–16 system originally planned for the network did not have adequate displays and controls for reliably acquiring the spacecraft in the acquisition time available. Consequently, a contract was negotiated with a manufacturer to provide the instrumentation radar acquisition (IRACQ) modifications. An essential feature of this modification is that it examines all incoming video signals, verifies the target, and automatically establishes angle-only track. Once the spacecraft has been acquired, in angle range, tracking in the automatic mode can be achieved with relative ease. Other features of the IRACQ system included additional angle scan modes and radar phasing controls to permit multiple radar interrogation of the spacecraft beacon. The addition of a beacon local oscillator wave meter permitted the determination of spacecraft-transmitter frequency drift.

Early in the installation program, it was realized that the range of the Bermuda FPS–16 should be increased beyond 500 miles. With the 500-mile-range limitation, it was possible to track the spacecraft for only 30 seconds prior to launch-vehicle sustainer engine cut-off (SECO) during the critical insertion phase. By extending the range capability to 1,000 miles, the spacecraft could be acquired earlier, and additional data could be provided to the Bermuda computer and flight dynamics console. This modification also increased the probability of having valid data available to make a go—no–go decision after SECO.

The Verlort radar (see figs. 8–3(a) and 8–3(b)) fulfilled the S-band requirement with only a few modifications. Significant ones were the addition of specific angle-track capability and additional angular scan modes. At Eglin Air Force Base the MPQ–31 radar was used for S-band tracking by extending its range capability to meet Mercury requirements. The data-handling equipment was essentially the same as for the FPS–16. Coordinate conversion and transmitting equipment was installed at Eglin to allow both the MPQ–31 and the FPS–16 to supply three-coordinate designate data to the AMR radars via Central Analog Data Distributing and Computing (CADDAC).

After implementation these radar systems performed as planned, and only minor modifications were made.

#### Active Acquisition Aid

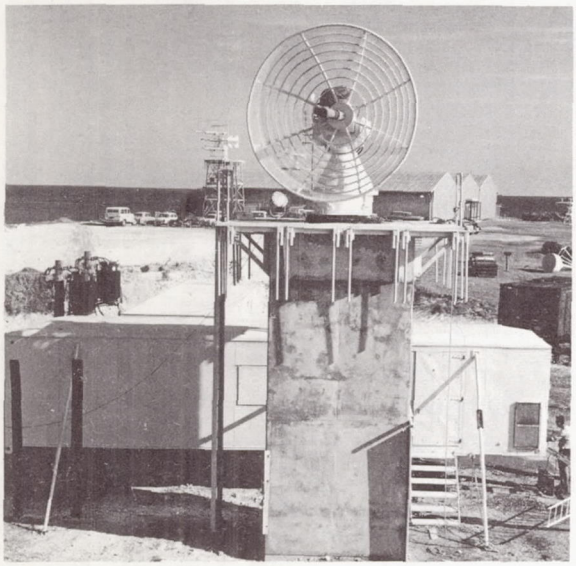
Once the types of radars to be used were determined, it became evident that these narrow-beam, precision-tracking units would have difficulty in initially acquiring the small, high-speed spacecraft. Without externally supplied dynamic pointing data, the spacecraft would pass through the radar beam so quickly that the basic radar circuits and/or operators would have very little time in which to recognize the target and switch into automatic tracking.

Two basic types of solution to the radar-acquisition problem were considered. One was the use of an on-site analog computer which

would be supplied with predicted spacecraft time and position data by teletype from the Goddard computers. The on-site computer would then generate dynamic-tracking data along the predicted orbit and supply it to the radar during the passage of the spacecraft. This approach was rejected because of the cost and development time necessary to provide suitable analog computers and because it was felt that complete dependence on teletype data for acquisition would not provide sufficient overall tracking system reliability.

The second solution to the problem was a new development called the "active acquisition aid." This device was designed to receive the spacecraft telemetering signals and automatically track the spacecraft in angle with sufficient accuracy to provide suitable pointing data to the radar.

The hardware to meet these requirements was developed around refurbished and modified SCR–584 radar pedestals, antenna, and receiver components. The major units of the final configuration used for Mercury are shown in figure 8–4, and figure 8–5 shows the acquisition aid antenna installation at Guaymas, Mexico.



(a).—Verlort installation at Bermuda.



(b).—Interior view of a Verlort radar van.

FIGURE 8–3.—Photographs of Verlort installations.

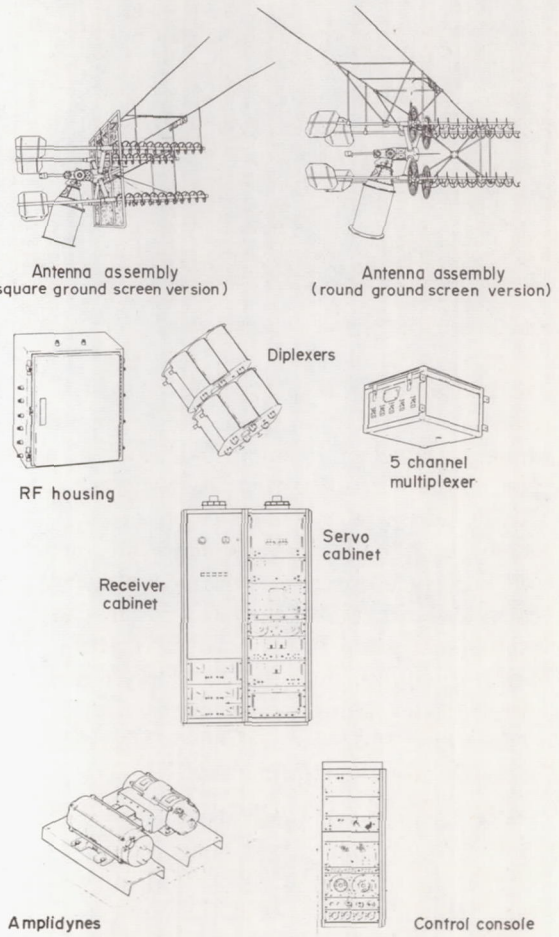



FIGURE 8–4.—Major units of the acquisition system.

*Performance analysis.*—Tests of the first systems delivered showed two major performance deficiencies. The first of these stemmed from the fact that the spacecraft-telemetering transmitter bandwidth was substantially wider than had been anticipated; the acquisition aid receiver was consequently unable to achieve phase lock. This deficiency was corrected by adapt-

ing another existing detector design to the Mercury equipment.



FIGURE 8–5.—Acquisition aid antenna installation at Guaymas, Mexico.

The second major performance problem was that the equipment could not meet tracking accuracy specifications on a continuous basis. Two principal factors contributed to the accuracy problem. The predominant one, especially at low and medium elevation angles, was that of multipath signal reception. The lesser factor was the inherent coarseness of the quadhelix antenna array and other RF components. Redesign of the antenna would have pushed beyond the state of the art and probably would have delayed the program. Use of another, existing antenna with less beamwidth and therefore less multipath susceptibility would, of course, have meant some sacrifice of one of the most desirable advantages of the system: that of being able to cover large areas of space in a short period of time.

Fortunately, early experience with the radars, particularly the FPS–16 which, equipped with the IRACQ modification, can lock on a target very quickly, indicated that the accuracy requirements of the acquisition aid could be relaxed; analysis of tracking requirements showed that with proper alinement, the equipment would provide sufficiently accurate data to the radars. The specified accuracy for the active acquisition aid was thus relaxed to require only tracking within the beamwidth of the particular radar with which it worked ($\pm 0.5°$ for the FPS–16 and $\pm 1.0°$ for the Verlort) for 2 seconds out of every 5 instead of $\pm 0.5°$ on a continuous basis.

With these changes, the initial performance deficiencies of the system were alleviated. However, in the course of the project, a number of other modifications to the equipment were found necessary to improve reliability, ease of maintenance, and ease of operation. Installation of hermetically sealed RF components, waterproof connectors, better antenna limit switching and mechanical limit stops, and bias regulators for the RF amplifiers was made to improve reliability. Test points and grounding switches in the voltage-controlled oscillator (VCO) and a connector board with many of the system test points in one convenient location were installed to improve the ease of maintenance. Changes to the antenna handwheels, relocation of controls, and installation of mode switches were made to increase the ease of operation.

In conclusion, it should be noted that although a number of problems of varying degrees of seriousness were encountered with the acquisition aid—most of them stemming from the necessity of developing a new system in an extremely short time—the equipment successfully fulfilled its intended function. Rarely during the latter Mercury missions did one of them fail to acquire and track the spacecraft shortly after horizon time and thereby aid the radar in acquiring an automatic track.

### Computing System

*Requirements.*—Early in the design of the Mercury system it was considered mandatory to receive information on a real-time basis and to provide for instantaneous computation and display of mission data from lift-off to landing. To meet these requirements, new data transmission equipment and computer peripheral gear were required. A new concept in large-scale, real-time data processing was required to tailor computations to a computer cycle and to manage the priorities of the computations performed automatically.

In all phases of the Mercury mission, it was vital that the many different forms of calculations be performed with exact precision and the data be made available almost instantaneously. For example, in a matter of seconds after launch-vehicle cut-off and spacecraft insertion into orbit, the computers were required to furnish data based on tracking information for evaluating whether or not the mission should be permitted to continue.

Before the Bermuda submarine cable was installed, it was decided to supplement the Goddard-Cape Canaveral complex with a secondary computing station at Bermuda. Installed there was an IBM 709 computer that received the inputs of the Bermuda FPS–16 and Verlort radars. The role of Bermuda was twofold: it served as a backup remote control center during the launch phase and as a tracking site thereafter. Specifically, it performed the following computing tasks:

(1) Provided all the necessary trajectory information to drive the display devices in the Bermuda control center.

(2) Computed an independent go—no–go at insertion based on Bermuda data.

(3) Computed retrofire times to be used in the event of an abort to land the spacecraft in one of the designated recovery areas.

(4) Computed refined landing points for several abort cases.

(5) Computed orbital characteristics.

(6) Sent postinsertion conditions to Goddard.

After the submarine cable was installed in April 1962, the Bermuda computer was removed and all the computations listed above were programed in the Goddard computers.

*System description.*—Since the computing system was described in a prior publication (ref. 2), only a brief review is presented here.

During a mission, radar data from the network stations are transmitted by way of data circuits (ref. 2) to the communications center (fig. 8–6). Here, real-time equipment places the radar data from each tracking station automatically in the core storage of the computers. Two IBM 7094 computers operating independently, but in parallel, process the data. Should a computer malfunction during the mission, the other computer can be switched on-line to support the mission while the malfunctioning computer is taken off-line and repaired.

The computers provide trajectory information necessary for the flight control of the mission. At MCC, about 18 digital displays, 4 plotboards, and the wall map (fig. 8–7) are driven by the computers. This map shows the present position of the spacecraft and the landing point which would be achieved if the retrorockets were ignited in 30 seconds.

*Development of new equipment.*—To implement a real-time computing system of the complexity of the one considered for Project



FIGURE 8–6.—Computing center at Goddard Space Flight Center.



FIGURE 8–7.—View of Mercury Control Center showing wall map, plotting boards, and digital displays.

Mercury, it was necessary to design some specialized equipment. An example is the IBM 7281 Data Communications Channel (DCC) which automatically accepts inputs from a large number of data sources, places the information quantities directly at the disposal of the computer, automatically accepts calculated output data from the computer, and makes the information immediately available for transmission to many destinations.

For early missions, a duplexed configuration of IBM 7090 computers was connected by a DCC to radar stations, and sources comprising the real-time tracking and instrumentation system. For the MA–9 mission, a Triplex configuration of IBM 7094 computers, which were updated from the IBM 7090 configuration, was used.

*Test and evaluation techniques.*—Any system as complex as the Mercury network had to be thoroughly tested under conditions as close to actual operating conditions as possible. It had to be certain that the units and subsystems were functioning properly and that all elements were functioning together as a complete system. Thus, it was necessary to devise computer-controlled tests to check out all computer-related elements of the total system. Called CADFISS (Computation and Data Flow Integrated Subsystem) testing, this worldwide network test concept was employed in Mercury launch countdowns to determine final tracking and data processing system readiness.

*Performance analysis.*—A brief analysis of how the computing and data system performed during the manner orbital Mercury missions is presented.

Table 8–I shows FPS–16 and Verlort radar performance. Both radars approached their design limits while tracking an orbital target. The values were derived by fitting the data to the equations of motion. The data were far better than expected. Note that, up until the MA–9 mission, the standard deviation in elevation for the FPS–16 is twice that in azimuth, probably as a result of refraction errors. An improved correction for refraction was incorporated into the Mercury programs for MA–9. This is not apparent in the Verlort; apparently the much higher noise level concealed the refractive error. In many cases the data from certain FPS–16 and Verlort radars were better than the 0.1 mil and 1.0 mil criteria.

A comparison of the single-station FPS–16 orbital determination with the single-station Verlort solution shows that the FPS–16 is roughly four times as accurate in position and eight times as accurate in velocity determination.

The accuracy of the Mercury integration scheme, atmospheric model, and tracking data is demonstrated in table 8–II. The orbit, as determined by multiple station solution, was integrated forward to compare with newer tracking data. The vector changes in position and velocity were averaged and are presented in table 8–II.

The accuracy of the total system is demonstrated by the calculation of time-to-fire retrorockets. The spacecraft timing system is such that the rockets are fired at the integer second. With the spacecraft traveling at 5 miles per second, the landing point is known only to ±2.5

*Table 8–I.—Radar Performance*

| Mission | Standard deviations—mission averages | | | | | |
|---|---|---|---|---|---|---|
| | FPS–16 | | | Verlort | | |
| | Range, yd | Azimuth, mils | Elevation, mils | Range, yd | Azimuth, mils | Elevation, mils |
| MA–6 | 8. 5 | 0. 23 | 0. 44 | 29. 0 | 1. 63 | 1. 35 |
| MA–7 | 9. 8 | . 22 | . 40 | 33. 7 | 1. 62 | 1. 72 |
| MA–8 | 8. 6 | . 25 | . 36 | 39. 6 | 1. 22 | 1. 34 |
| MA–9 | 11. 2 | . 27 | . 26 | 20. 2 | 1. 36 | 1. 42 |

miles. The recovery forces are able to estimate their position to about ±2 miles. Thus, the total uncertainty may be approximately ±5 miles. Table 8–III shows the landing points predicted for the four manned missions. The center column shows the landing point established by radar tracking. The tracking information in MA–7 and MA–6 provided landing points within 15 to 20 miles of that reported by the recovery forces. This difference may have resulted from lift experienced by the spacecraft in reentry. The predictions for MA–8 and MA–9 are well within the area of uncertainty and show a nearly perfect retrofire and reentry.

Several years ago, a prediction such as that shown in table 8–III would have appeared very optimistic for the performance of the manned space-flight network. In considering performances as a whole, the network can be said to have performed considerably better than originally anticipated. The network tracking and computing system has successfully predicted the spacecraft landing points, and at all times has provided accurate information on the astronaut's position. For all of the Mercury missions, the network and computing system performed their basic functions normally and without exception.

*Table 8–II.—Average Change in Position and Velocity*

| Mission | Change in position, yd | Change in velocity, ft/sec |
|---|---|---|
| MA–6 | 265 | 0.9 |
| MA–7 | 266 | 1.1 |
| MA–8 | 217 | 1.0 |
| MA–9 | [a]220 | [a]1.6 |
| | [b]1,040 | [b]4.5 |

[a] First three passes
[b] Mission average—no data on 15 of 22 passes

### Telemetry

Because the telemetry system has been described in reference 2, this section briefly describes only the design approach, modifications, and performance. To help orient the reader, a typical antenna installation at a telemetry station is presented in figure 8–8, and display and control consoles aboard a telemetry ship are presented in figure 8–9.

*Table 8–III.—Results of Landing-Point Predictions Made by Computers*

| Mission | Predicted landing point | Reported pickup point of spacecraft |
|---|---|---|
| MA–6 | 21°31.2′<br>68°52.9′ | 21°25.6′ N.<br>68°36.5′ W. |
| MA–7 | 19°24′ N.<br>63°52′ W. | 19°30′<br>64°15′. |
| MA–8 | 32°06′ N.<br>174°31.8′ W. | 32°05.5′ N.<br>174°28.5′ W. |
| MA–9 | 27°22′ N.<br>176°29′ W. | 27°22.6′ N.<br>176°35.3′ W. |

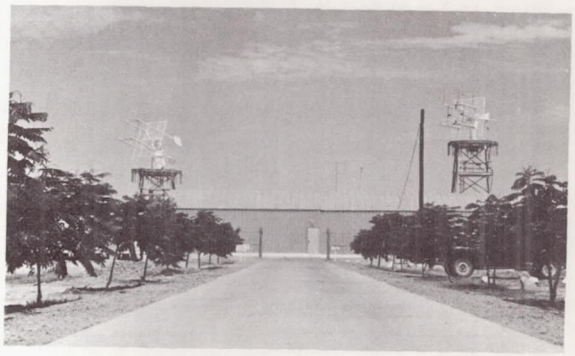


FIGURE 8–8.—Antenna installations for the Telemetry and Control (T and C) Building Area, Guaymas, Mexico.



FIGURE 8–9.—Display and control consoles aboard the Rose Knot.

*Design approach.*—Obviously, the ground-station design requirements were established to be compatible with the spacecraft's telemetry characteristics. The basic type of telemetry system chosen early in Project Mercury was PAM/FM/FM. This system was chosen because it could provide the needed information

and was a reasonably well proven state-of-the-art type which could be implemented on the ground stations with commercially available hardware. Implementation guidelines used are as follows:

(1) Two independent links were to be used to gain reliability. The equipment at each station was to provide independent receiving systems for the two links from the spacecraft. Separate preamplifiers, receivers, diversity combiners, filters, subcarrier discriminators, and the associated monitor and control equipment were to be provided. Separate monitoring of the data from the subcarrier discriminators of each system with commutated data not decoded was to be provided to permit the operator to select the telemetry system output to be displayed at a main control console.

(2) At the stations which were to have command transmitters, separate decoding and display equipment was to be provided for the two telemetry links. (This arrangement was necessary to provide reliability in determining that the proper commands were received at the spacecraft.) At all other sites, only one set of decommutation and output data display equipment was to be provided, with appropriate switching to the output of either receiving system.

(3) Provisions were to be made for separate magnetic tape recordings of the received outputs from each telemetry system to permit playback and reassessment of the data following a pass. These recordings also were to provide a permanent record of the data with an overall accuracy of 1 percent.

(4) Data-output display equipment was to be provided with the appropriate meters, lamp indicators, and direct writing records.

(5) Continuous data on IRIG channels 5, 6, and 7 were to be recorded and displayed on direct writing strip chart recorders with an accuracy of 2 percent of full scale. Each of these channels was also to be provided with a suitable events-per-unit time display. (This provision was needed by aeromedical personnel to monitor the astronaut's heart action and respiration.)

(6) Individual data outputs of the analog quantities handled on the commutated subcarrier (PAM) were to be displayed on meters with an accuracy of 2 percent of full scale. Display of the events data carried on the commutated subcarriers was to be in the form of lights. Appropriate translation equipment was to be provided to display the time measurements as in-line decimal digits in hours, minutes, and seconds.

(7) Monitor displays were to be provided to permit the operator to assess the outputs of both receiving systems at a station and to select the system to drive the final data output displays.

(8) A permanent recording system capable of rapid processing and display was to be provided to record all subcarrier discriminator outputs, all decommutated analog quantities, and received signal strength.

(9) The overall system-accuracy requirement was that system error not exceed 2 percent under field conditions.

*System performance.*—The telemetry and display system performance was outstanding throughout the project. During controlled flight, coverage time was generally horizon to horizon. Missions which had periods of drifting flight caused occasional signal dropouts due to nulls in the spacecraft antenna pattern. During reentry phases, both telemetry links were attenuated by the ionized sheath created by intense heat and ablation of the heat shield and reception was completely lost for periods of 3 to 5 minutes.

System accuracy (to the displays) of 2 percent, as originally implemented, was met satisfactorily. Summary data from remote sites which included the degradation factors of 2-percent meters, meter parallax, short mission meter scales (e.g., utilizing 50 percent of full-meter scale deflection), and reading error were generally within $\pm 3$ percent of full-scale meter deflection.

#### Air-Ground Communications

A system was required at each site to permit direct communications with the astronaut. This system, termed the air-ground system, would comprise all of the ground-based transmitting, receiving, control, and antenna equipment required to establish two-way voice communications with the Mercury spacecraft. General requirements included communications reliability, ease of rapidly restoring system operation in case of failure, and the use of proven

off-the-shelf equipment to reduce both delivery time and costs. The following paragraphs describe the specific requirements for this system, the system modifications, and a summary of system performance.

*Requirements.*—To provide a highly reliable system of communications which would be able to overcome difficulties arising from spacecraft equipment failure, atmospheric disturbances, and ground-equipment breakdown, the following specific requirements were established:

(1) Complete voice transmission and reception facilities for both HF and UHF operation were to be provided, with the HF equipment to serve as a backup facility for the UHF.

(2) Standby UHF transmitters were required for backup purposes at all stations.

(3) Standby HF transmitters were required for backup use at certain critical stations.

(4) Remote and local transmitter control was required for all transmitters.

(5) The means for operating these transmitters on tone modulation as well as voice was required.

(6) At those sites equipped with command transmitters, a voice-modulation capability for the command transmitters was required as an emergency mode of operation.

(7) A means was required for individual operation of the UHF, HF, and emergency-voice modes, as well as simultaneous use of the UHF and HF or the UHF, HF, and emergency-voices modes.

(8) At sites where transmitting equipment was to be installed in vans, provisions for moving the van from the transmitting antenna to a receiving antenna were required in case of transmitting antenna or pedestal failure.

(9) To offset space-fading effects and also to provide built-in equipment backup facilities, dual space and polarization-diversity equipment was required for UHF reception, and dual-space diversity equipment was required for HF reception. This stipulation, then, required that two complete and identical sets of antennas, transmission lines, and receiver elements for both the HF and UHF equipment be furnished at each site.

(10) Circular polarization of UHF transmitting and receiving antennas was required to offset signal attenuation caused by any skew attitude of the spacecraft antenna with relation to the ground antennas.

(11) Recording facilities were required for all transmitted and received audio.

(12) Varied distribution of all received audio and transmitter sidetones was required through monitor speakers and the station intercom system in order to satisfy the site operating requirements.

*Performance.*—UHF was used for primary voice communication throughout the project with very satisfactory results.

Because of wave propagation, HF communication proved too intermittent to be used as more than backup communication and could not be considered as a reliable means of extending communication beyond station horizon. The HF quality improved somewhat, however, after a dipole antenna was installed on the MA–8 and MA–9 spacecraft.

A photograph of the air-ground antenna and transmitter van installed at Guaymas, Mexico, is shown in figure 8–10.

### Command

*Requirements.*—The criteria for the command equipment followed the general guide lines for all Mercury equipment. The basic requirement was the transmission of commands from certain stations to the spacecraft in order to provide a command backup for the manually controlled or internally programed events in the spacecraft. The range coverage of the command system was to be limited only by line-of-sight conditions to the spacecraft. The minimum normal range of the systems was originally set at 700 nautical miles.

This equipment was to employ a suitable coding technique to provide high reliability with particular attention to prevention of incorrect commands because of noise, interference, or transmitting equipment failures. All command sites would have dual FRW–2, 500-watt transmitters. The command antenna was to have at least 18-db gain, circular polarization, and to be steerable.

*Modifications.*—Bermuda, having coverage of the critical insertion phase, required the ability to "brute force" command signals to the spacecraft regardless of the spacecraft an-

tenna position. A 10-kw RF power amplifier was to be provided for that purpose. Likewise, monitoring facilities that would provide failure sensing of this power amplifier were required. If failure occurred, antenna transfer to the operational 500-watt transmitter would be done automatically. Three existing sites already had this high power and failure switching capability.



FIGURE 8–10.—Transmitter van and antenna installation at Guaymas, Mexico, for command and air-ground voice.

It was necessary to remove the standard coder controller of the FRW–2 and substitute coder control units designed to be compatible with the coding technique employed in the spacecraft equipment and the input requirements of the FRW–2 coder KY–171/URW coder which was part of the FRW–2. Furthermore, the coder controllers were to be capable of remote activation and rapid changeover to any one of several codes which might be desired.

During the implementation phase of the program, ancillary equipment consisting of control and monitoring facilities was designed and fabricated. This equipment was necessary to provide the desired fail-safe features and degrees of flexibility this program required. Furthermore, at sites equipped with command vans, provisions were made to allow the transmitter van to be moved to the receiver antenna pedestal in case the command antenna pedestal failed.

Mission requirements made major command equipment additions necessary. The need for additional command coverage became apparent when the program was expanded beyond three-orbital-pass missions. Consequently, dual 10–kw command facilities were installed on the Rose Knot Victor telemetry ship. The basic equipment furnished was identical to that furnished previously to the land-based stations. Temporary dual 500-watt command facilities were also added to the Coastal Sentry Quebec Ship. Here again, the basic equipment furnished was identical to existing land equipment.

Another major change in the command configuration was the MCC-Bermuda tone remoting system which became practical only after submarine cable circuits were available between Bermuda and Cape Canaveral.

*Performance.*—As with the other systems, the command equipment functioned as planned throughout the project.

### Ground Communications

*Introduction.*—Operation of this system was discussed in reference 2; therefore, it is only briefly reviewed in the present paper. Again the basic design criteria were used: reliability, cost, and speed of implementation.

*Requirements.*—A primary requirement for the tracking network was that the stations be tied together with an adequate and reliable communications center. This center was to act as the heart of a communications system which would perform the following functions:

(1) Transmit acquisition information from the computing center to the tracking and telemetry stations.

(2) Transmit commands and instructions from the MCC to the stations.

(3) Transmit digital tracking data from the tracking stations to the computing center.

(4) Transmit telemetry summary messages from the stations to the MCC.

(5) Provide high-speed data transmission between the computing center and the MCC for display purposes.

(6) Provide voice communications capability between certain stations and the MCC.

(7) Transmit mission teletype traffic throughout the network.

Both teletype and voice circuits were required. The teletype circuits usually operated at 60 words per minute and provided for transmission of all of the required types of information except high-speed tracking data and, of course, voice communications. These two were handled by voice-quality circuits with a pass band of 280 to 2,800 cps.

The network that was established to meet these requirements is illustrated in reference 2.

Because these channels traverse extremely long distances and employ a variety of transmission media, such as land lines of various types, submarine cables, and HF radio, it was necessary that the design arrangement and operating technique preserve their transmission capability. The chief factors involved were overall attenuation, bandwidth, distortion, noise, return loss, and echo.

*Modifications and Performance.*—Following are some of the major changes made after the initial configuration was established:

(1) The HF link to Bermuda was dropped after the cable became available, and two high-speed data circuits from Bermuda to Goddard were added.

(2) The network was expanded to include the switching, conferencing, and monitoring (SCAMA) voice capability to Canary Island, Kano, Zanzibar, Canton Island, the Rose Knot Victor, and the Coastal Sentry Quebec.

(3) Zanzibar became a primary HF link for the Coastal Sentry Quebec.

(4) HF backup to Guaymas was added.

The Mercury communications network included 102,000 miles of teletype lines, 60,000 miles of telephone lines, and 15,000 miles of high-speed data lines.

The ground communication system operated very satisfactorily for all missions. Performance figures for the MA–7 and MA–8 missions are listed in table 8–IV.

*Table 8–IV.—Messages Handled During MA–7 and MA–8*

| | MA–7 | MA–8 |
|---|---|---|
| Total number of messages | 1, 814 | 5, 587 |
| Information flow time, min | Messages | Messages |
| 0 to 5 | 1, 597 | 4, 335 |
| 5 to 10 | 169 | 878 |
| Over 10 | 24 | 334 |
| Undetermined | 24 | 40 |
| Message transmission time, min | | |
| 0 to 1 | 526 | 1, 073 |
| 1 to 2 | 625 | 2, 087 |
| 2 to 3 | 410 | 1, 151 |
| 3 to 4 | 128 | 569 |
| 4 to 5 | 40 | 134 |
| Over 5 | 75 | 515 |
| Undetermined | 10 | 58 |
| Garbled messages | 2 | 2 |
| Lost messages | 0 | 0 |

### Timing

A timing system was required to provide timing signals for all recorders in a common format, binary-coded time signals for radar data, strobe pulses for radar interrogation, and outputs for driving wall clocks and displays. The system was to have the capability of synchronizing with WWV timing with a resolution accuracy to within 0.001 second. The stability of the timing system was to be such that the local timing oscillator drift would not exceed 0.001 second in 48 hours.

The timing system which had been developed for the scientific satellite tracking stations was selected since it had proved to be reliable and accurate under actual field operating conditions.

The timing system performed satisfactorily throughout the Mercury Project, and only minor modifications were necessary to correct component failures and increase reliability.

### Intercom

It was apparent at the outset that rapid and flexible voice communications (intercom) would be needed within each station. Station personnel who would need such communications were (1) the flight controllers, who would monitor the flight status of the spacecraft and the overall conduct of the mission and who would advise and assist the astronaut in making decisions as required, and (2) the maintenance and operations personnel, who would provide technical support to the flight controllers in the operation of the various tracking, telemetry, and communications systems.

The intercom system had to have the capability of interconnecting several different consoles or positions in a conference type circuit (loop) whereby several people would be able to carry on a discussion, with others being able to "listen in" or be called on for comments or information. Also, because of the varied activities of different positions, there had to be several of these conference loops so that simultaneous conversations could be carried on with each loop usually isolated to one system or activity. The system also had to connect to outside lines so that the flight director could have immediate contact with any of the flight controllers at any station through the world-wide communications network.

After implementation by using standard components, only a few minor modifications to the intercom system were necessary to obtain proper, reliable operation. The system met the project requirements in a first-rate manner.

### Control Centers

*Mercury Control Center.*—The primary function of MCC was to provide a means of centralizing control and coordination of all the activities associated with a Mercury mission. Figure 8–11 is a view of the operation room of MCC. Mission control and coordination were conducted from MCC beginning at approximately 10 to 12 days before lift-off and continuing through the launch, orbital, reentry, and recovery phases. Communication, display, and control capability for MCC operation was provided in the various consoles, which are shown in figure 8–12. Many of the positions contained duplicate displays and controls to provide redundancy which was considered essential to the Mercury Project.

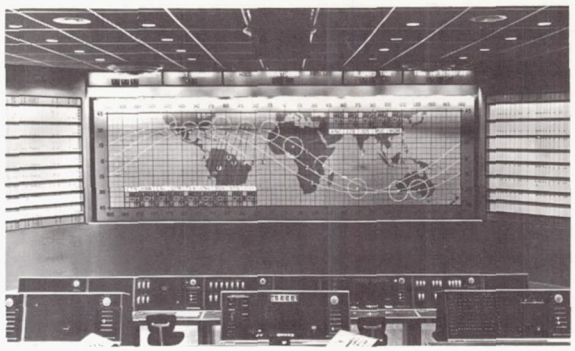


FIGURE 8–11.—Mercury Control Center as viewed from the observation room.

*Bermuda Control Center.*—In the earlier phases of the project, this secondary control center was required because the critical orbital insertion point of the spacecraft would be at a marginal distance and low-elevation angle from MCC, which might give unreliable data and would allow little time for MCC to determine go—no–go conditions. In addition, since Bermuda's vital tracking data needed for establishing insertion parameters had to be relayed by HF, a more fail-proof arrangement was needed. The Bermuda Control Center had the following basic functions:

(1) To command an abort in the event of critical spacecraft equipment failure or pilot difficulty late in the launch phase.

(2) To command an abort as directed by MCC in the event of certain propulsion or guidance system malfunctions.

(3) To control the mission independently in the event of communications failure with MCC.

Figures 8–13 and 8–14 show a view of the center and an equipment layout.

After the submarine cable to Bermuda was available, it was possible to remote the control data safely to MCC. The Bermuda station functioned as a remote station for the MA–9 mission with a minimum of flight-control staff.

### Simulation Equipment

The development of a simulation system was established primarily to answer the need for an active training device for mission flight controllers. A secondary use for the simulation

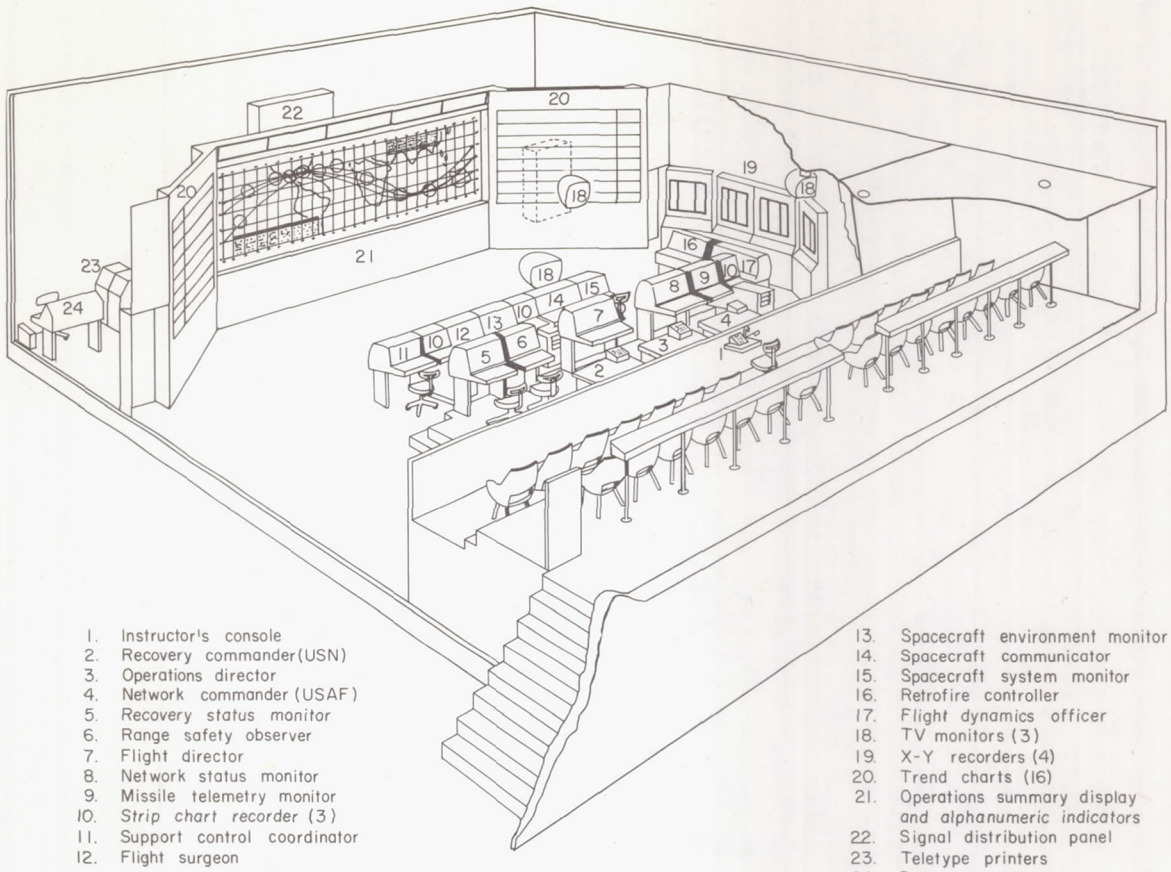



FIGURE 8–12.—Operations Room and Observation Room, Mercury Control Center.



FIGURE 8–13.—View of Bermuda Control Center.

system was the familiarization of the maintenance and operating personnel with the mission support required of them for a particular flight.

The simulation system was designed in two parts: the first and major part was the addition of specialized instrumentation and control consoles at MCC that could be used by instructors to provide the stimulus necessary to activate the MCC operational consoles; the second part was a separate remote-site simulator for the purpose of training flight controllers who would be ultimately assigned to stations other than the control center.

### Equipment Documentation

Within a general requirement to furnish adequate instruction manuals for the network equipment, detailed specifications for individual manuals were prepared and the overall organization of this family of documentation was developed. The detailed specification called for new manuals to be prepared in accordance with the best commercial practices and established minimum content requirements for the acceptance of existing, off-the-shelf manuals. The most notable feature of the overall organization of the manuals was the concept of system manuals and equipment manuals. Equipment manuals covered individual units and subsystems, such as communications receivers, audio line amplifiers, and radar sets; and system manuals

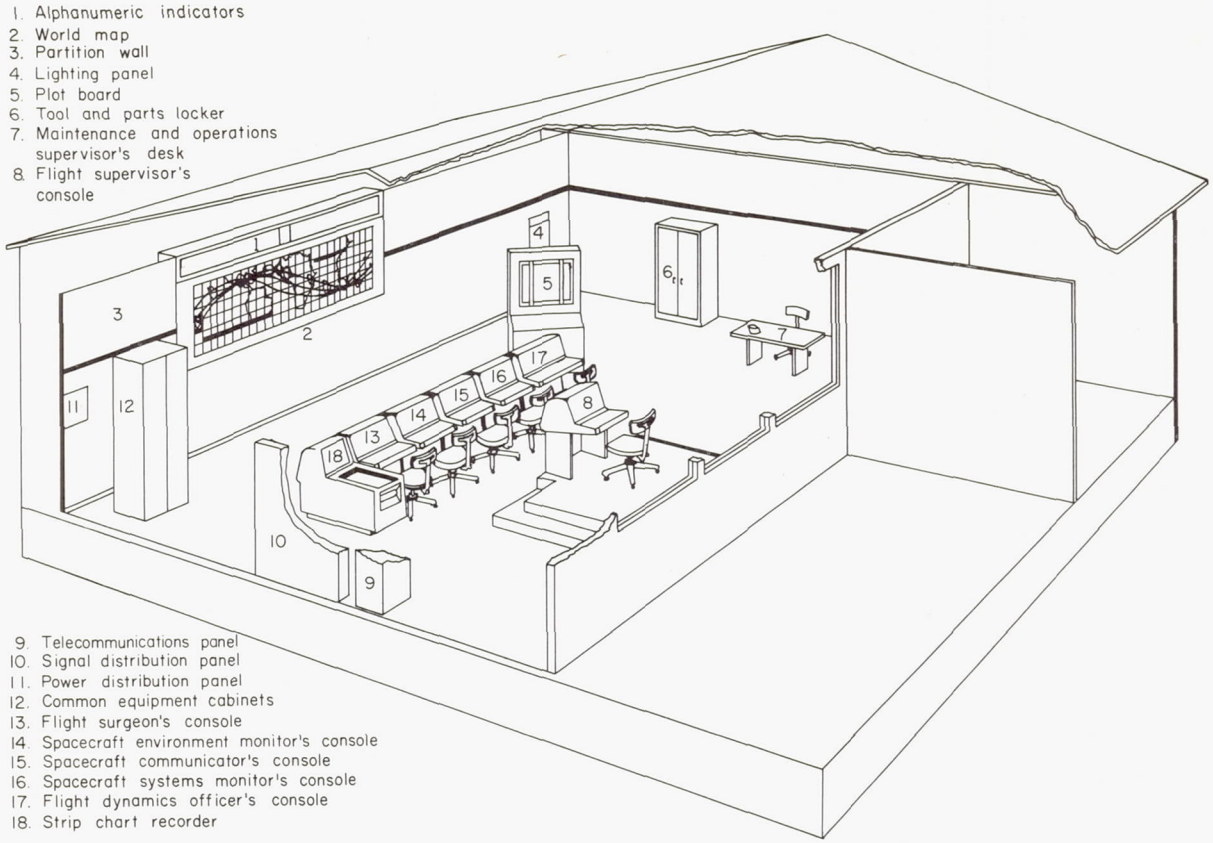



FIGURE 8–14.—Operations Room, Bermuda.

provided information on how the individual units and subsystems tied together to form the major network system. Altogether, approximately 450 separate manuals with copies totaling nearly 50,000 were supplied for use on the network.

### Installation

The installation of ground instrumentation equipment actually began with the efforts of the teams who selected the sites for the remote stations. The general area for each station had been determined from the planned orbit charts, but selected areas required on-site inspection for the evaluation of local problems and land availability. Each station had to be considered from cost, adaptability, and accessability standpoints. Every attempt was made to use existing facilities, but where these were not available below the orbital paths, sites were chosen which presented the fewest problems while satisfying the necessary criteria.

The Project Mercury tracking stations required considerable land area to provide necessary isolation (separation) between transmitting and receiving antennas. The equipment covered a very wide range of frequencies and required specific terrain configurations to operate at maximum efficiency. It was determined that five of the stations and the control center could be located on national ranges where use could be made of existing facilities. One new station was to be located in Texas and two on shipboard. The remaining eight would have to be established on foreign or overseas territory.

Selection of the foreign locations was accomplished by two teams. The first, a management team which had representation from the U.S. Department of State, was to determine and resolve, if possible, all difficulties of a general nature such as political considerations, preference of local officials as to station location, and currency problems. In addition, contact was made with local contractors, material suppliers, and service companies. Labor sources were also investigated and data on living conditions were obtained. The management team selected

a preferred and an alternate location for each station.

Data gathering was the prime function of the technical survey teams. Project personnel spent several days at each prospective site checking soil conditions, topography, water, sewage disposal, communications, transportation, electric power, and climate. A comprehensive report prepared on each site provided the basis for station selection and was used thereafter as a guide for equipment design and location.

The tight schedule made it impossible to stagger construction at the various stations. Although first construction operations were not started until April 29, 1960, all stations were under construction by midsummer, and construction was completed at the last station in Kano, Nigeria, in March of 1961.

Most buildings were constructed of prefabricated galvanized sheet metal supported by rigid steel frames. In addition to the buildings housing electronic equipment, most stations contained power buildings, cooling towers, air handlers, water chillers, and hydropneumatic tanks. Diesel generators were installed to produce power to back up commercial power.

Extreme precision was necessary in the positioning of every radar antenna. Each unit had to be surveyed to determine true latitude and longtitude with exact interrelation, and angles were established with a maximum allowable deviation of 6 seconds.

As construction of facilities was still underway at some stations, the equipment and the installation teams were arriving. The number of installers on a site team varied between 5 and 25, depending on the amount of equipment to be installed. A typical team consisted of the site manager, the team crew chief, a lead man for a subsystem or a combination of subsystems, several technicians, and one or two subcontractor advisors for specialized areas such as the acquisition system. Each team was also supported by a logistics man.

All installation team leaders were authorized to work with the local labor unions and utilize the local labor market to perform certain jobs beyond the capabilities of the installation team and its facilities.

Two depots—one on each coast of the United States—were established to provide logistics support for the overseas stations and to handle the customs details involved in such shipments. The depots served as staging areas for overseas shipments, whereas equipment destined for stations in the United States was shipped directly from the manufacturer. More than 1,000 tons of cargo were processed through the depots, most of it in preassembled units. A rigid receiving and inspecting system was set up at each station to check in all equipment before it was turned over to the installation team.

Spare parts provisioning was another logistics consideration. There had to be a reasonable on-site repair capability. Each industry team member supplied a 2-year supply of spares unique to his equipment and a list of recommended common item spares. From these lists a combined list of common item spares was drawn up to eliminate duplications. Common item spares were procured in accordance with the combined list and shipped to each site.

Thus, the concept of a network of stations became a reality with equipment and logistic support. The scope of design, construction, installation, and activation for the Mercury Network is shown in figure 8–15.

Figure 8–16 shows construction underway at Kano.

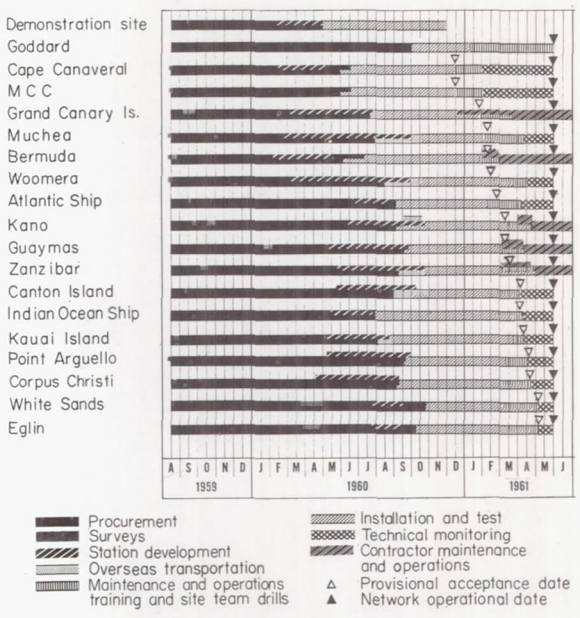



FIGURE 8–15.—Overall Mercury Network schedule.

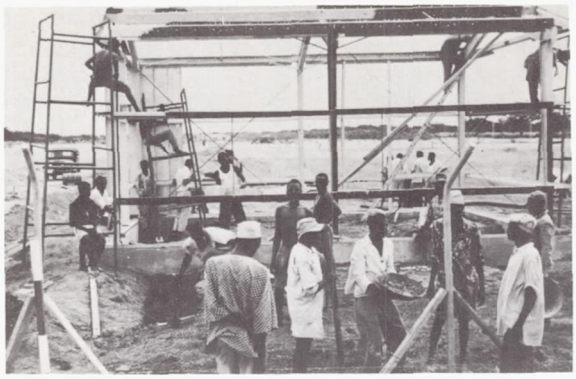


FIGURE 8–16.—Construction of the receiver building Kano, Nigeria.

### Testing

*Demonstration site.*—The necessity of testing and evaluating the ground instrumentation equipment as a complete system prior to its installation on a worldwide basis was recognized in the early planning stages of the Mercury Project. Equipment from more than 10 major manufacturers plus numerous subcontractors was involved, and it had to be determined that all interrelated problems had been solved and that the equipment would perform as a system.

The selection of NASA Wallops Station, Wallops Island, Virginia, as a test site was determined primarily because of its availability and its proximity to Langley Research Center at Langley Air Force Base, Virginia, and the Goddard Space Flight Center at Greenbelt, Maryland. A complete tracking station was installed, with the Mercury data conversion and acquisition equipment connected to the existing FPS–16 at the Wallops Station Launch Complex.

Representatives from the suppliers of equipment conducted tests at Wallops under NASA supervision. As a result of these tests, many changes were made to equipment in the prototype stage prior to worldwide deliveries. Also developed at the Demonstration Site were test procedures that were used throughout the network for acceptance testing of on-site equipment.

The test procedures were of four types:

(1) Mercury Unit Tests (MUT) were developed to provide acceptance of self-contained equipment such as the R–390 HF voice receiver or the Ampex FR–100B tape recorder. The unit tests covered every measurable aspect that could influence the reliability of minimum performance expected of the unit.

(2) Mercury System Tests (MST) were developed to provide acceptance of a complete system. These tests checked the action of each interfaced relay as well as system performance.

(3) Mercury Integrated Tests (MIT) were developed to provide acceptance of the station as an integrated complex. These tests assured successful interface of systems. They also revealed RF interference problems.

(4) Mercury Dynamic Tests (MDT) were developed to test the equipment under simulated operating conditions. As ground station equipment was installed and evaluated at the Demonstration Site, the need for a method of closely simulating spacecraft tracking soon became apparent. Small leased aircraft were used to check the tracking accuracy of the new acquisition aid, and it was found that certain modifications were necessary for the equipment to meet specifications.

*Instrumented aircraft.*—As a result of these and other special aircraft tests, it was decided that aircraft would be obtained and completely instrumented with actual spacecraft electronics (see fig. 8–17) to serve three functions:

(1) To qualify each ground system prior to worldwide equipment delivery so that compatibility between ground and airborne systems was assured.



FIGURE 8–17.—Interior view of aircraft showing a small portion of the test equipment.

(2) To provide a complete checkout of each station in the network so that operational readiness was determined.

(3) To provide continual testing and training throughout the Mercury Project.

#### Training

Prior to station assignment, selected senior engineers received specialized equipment training and later helped to install the equipment at the Demonstration Site. After assignment, these senior engineers were responsible for making their equipment operational and for indoctrinating the other team members. Training was largely accomplished by working with the equipment during installation and by playing an active role in conducting acceptance tests. As time allowed, semiformal classes were held in theory and maintenance.

*Formal training.*—Installation technicians were technically capable of performing maintenance, but operational requirements posed the need for a refinement of the team concept and a regimented reaction to the demands of mission accomplishment. Transition from installer and maintenance technician to operator was accomplished by a rigorous training program that included: formal indoctrination lectures on space-flight matters and on Project Mercury; on-the-job training combined with classroom drills covering operation of the equipment; local-station simulated missions; and network simulations using countdowns, live communications, and telemetry tapes.

The maintenance and operation capability of station personnel had to be continually upgraded, and replacement personnel had to be provided. Likewise, the station had to be exercised as an entity to assure that it could work as a cohesive unit during a mission.

*Training center.*—To upgrade individual capabilities and to provide replacement personnel, a training center was established at the Demonstration Site. The primary long-term objective of the Engineering and Training Center was to sustain or improve the level of competence of the personnel manning the Mercury network stations through a comprehensive training program in each of the equipment subsystems making up the station. It was also designed to give the necessary high-level training to replacement personnel so that network proficiency would not suffer from personnel attrition.

To supplement the training received at the center, cross-training packages of lesson guides, equipment exercises, and examinations were developed for use at all the Mercury network stations. These were used for training of personnel in secondary areas of responsibility to enhance the overall capability of each team at the stations.

### Network Configuration

#### Arrangement for MA–6

Up to this point, network requirements and systems development and implementation have been discussed. The types of systems available at each site are listed in table 8–V. To illustrate how a Mercury station was arranged, a line drawing of the Hawaii station layout is shown in figure 8–18.

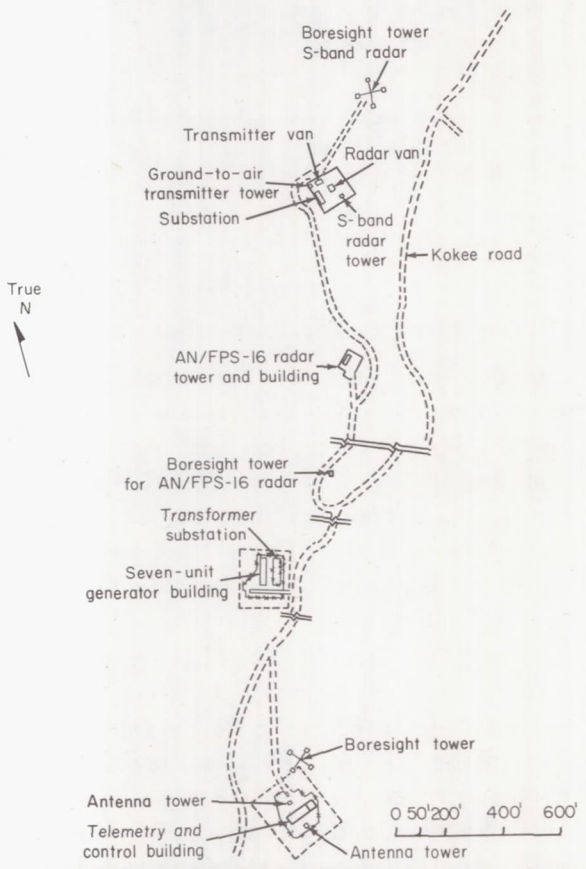



FIGURE 8–18.—Hawaii station layout.

*Table 8–V.—Station Equipment*

| Station | Command control | Telemetry reception | Air-ground voice | FPS–16 radar | Verlort radar | Acquisition aid | Computer | Ground communications | | Timing |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Voice | Telemetry | |
| Cape Canaveral (CNV–MCC) | x | x | x | x | | x | B/GE IP7090 | x | x | x |
| Grand Bahama Island (GBI)[a] | x | x | x | x | | | | x | x | x |
| Grand Turk Island (GTI)[a] | x | x | x | | | | | x | x | x |
| Bermuda (BDA) | x | x | x | x | x | x | IBM–709 | x | x | x |
| Atlantic Ship (ATS) | | x | x | | | x | | x | x | x |
| Grand Canary Island (CYI) | | x | x | | x | x | | x | x | x |
| Kano, Nigeria (KNO) | | x | x | | | x | | | x | x |
| Zanzibar (ZZB) | | x | x | | | x | | | x | x |
| Indian Ocean Ship (IOS) | | x | x | | | x | | | x | x |
| Muchea, Australia (MUC) | x | x | x | | x | x | | x | x | x |
| Woomera, Australia (WOM) | | x | x | x | | x | | x | x | x |
| Canton Island (CTN) | | x | x | | | x | | | x | x |
| Kauai Island, Hawaii (HAW) | x | x | x | x | x | x | | x | x | x |
| Point Arguello, Calif. (CAL) | x | x | x | x | x | x | | x | x | x |
| Guaymas, Mexico (GYM) | x | x | x | | x | x | | x | x | x |
| White Sands, N.M. (WHS)[b] | | | | x | | x | | x | x | x |
| Corpus Christi, Tex. (TEX) | | x | x | | x | x | | x | x | x |
| Eglin, Florida (EGL)[b] | | | | x | MPQ–31 | x | | x | x | x |
| Goddard Space Flight Center (GSFC) | | | | | | | IBM–7090 | Communications Center | | |

[a] No monitoring facilities; downrange antennas for MCC.
[b] Radar tracking station only.

**Major Changes for Succeeding Missions**

*Changes for MA–7.*—The second manned orbital flight, MA–7, was also planned as a three orbital pass mission. The network configuration was the same as that for MA–6 except for minor exceptions; there was no Atlantic Ship, and the Indian Ocean Ship was repositioned in the Mozambique Channel, off the east coast of Africa.

*Changes for MA–8.*—The MA–8 mission was planned to be a six orbital pass mission with landing to be made in the Pacific Ocean. For this mission, the former Atlantic Ship had a command system installed and was redesignated as the Pacific Command Ship (PCS) for positioning south of Japan. Three additional ships, the Huntsville, the Watertown, and the American Mariner, were made a part of the network and positioned near Midway to get reentry data.

*Changes for MA–9.*—Since it was decided to extend the length of the MA–9 mission to 22 orbital passes, it was necessary to modify the network so that adequate support could be provided. The following describes the changes that were required:

*Equipment:*

(1) All command sites were provided with additional command capabilities to give the site flight controllers the capability to turn on the spacecraft's telemetry transmitter, radar beacons, and an astronaut alarm. Other command changes included the addition of a complete system aboard the Coastal Sentry Quebec (CSQ) and an increase of the Rose Knot Victor (RKV) command power from 600 watts to

10 kilowatts. Figure 8–19 shows the two ships in the port of Baltimore for modifications.



FIGURE 8–19.—Rose Knot Victor and Coastal Sentry Quebec in Port Baltimore for MA–9 modifications.

(2) Mercury tracking site clocks showing "spacecraft elapsed time" and "time to retrofire" were modified to extend their reading time.

(3) Additional equipment was installed at California and Bermuda, allowing biomedical data to be sent (over land lines) to MCC display consoles.

(4) A telemetry automatic processing system that used a small general purpose computer (AN/UYK–1) was installed at Bermuda. The system was designed to accept PAM/FM/FM frames of 88 parameters every 800 milliseconds in real-time and generate special and regular summary messages. The output data were in a format which represented selected parameters in engineering units. A running tolerance check of all parameters was included and selected data were stored for postpass analysis.

(5) Receivers were installed at MCC, Canary Island, and the CSQ for reception of the slow-scan TV picture from the spacecraft. The installation at MCC and on the CSQ included record and display capabilities, whereas the installation at CYI was for record only.

(6) An additional IBM computer was added to the computer complex at GSFC, and the two 7090's already in operation were converted to 7094's.

*Communications:*

(1) The radio links to BDA were discontinued since the submarine cable was now operational.

(2) Communications to the CSQ at the new location were handled through a radio link which could operate through either Honolulu or Bassendean and thence by the usual path.

(3) Communications to the RKV were handled by RF links to Honolulu and New York.

(4) A new circuit was added to relay the Range Tracker data through Honolulu.

(5) The mission message format was changed to improve circuit operation and to facilitate accumulation of more data.

(6) New equipment arrangements were instituted at Goddard to permit CADFISS and operational programs to be conducted simultaneously.

*Relocation of ships:* The Coastal Sentry Quebec was relocated to the approximate position of 28°30′ N. latitude and 130°00′ E. longitude. The primary purpose of this location was to provide adequate retrosequence command back-up during the 6th, 7th, 21st, and 22nd orbital passes.

The Rose Knot Victor was relocated to the approximate position of 25°00′ S. latitude and 120°00′ W. longitude. In this position, it provided optimum command coverage for passes not covered by other network sites. The RKV provided coverage with its 10-kw command transmitter during the 8th and 13th orbital passes.

*Additional support:* To provide the necessary coverage to support a mission of this duration it was necessary to add the following tracking facilities:

(1) The Range Tracker (C-band radar equipped ship) was stationed at 31°30′ N. latitude and 173°00′ E. longitude to provide reentry radar coverage for the 4th, 7th, and 22nd orbital passes.

(2) The Twin Falls Victory (C-band radar equipped ship) was stationed in the vicinity of 31°3′ N. latitude and 75°00′ W. longitude for reentry radar coverage for the 2nd and 17th orbital passes.

(3) The Ascension Island station provided FPS–16 radar tracking during the fourth orbital pass. Also provided were telemetry recording, air-ground relay, and ECG remoting.

(4) The East Island, Puerto Rico, station provided FPS–16 radar tracking.

(5) The Antigua Island station provided telemetry recording, air-ground relay, and ECG relay.

(6) Air-ground voice facilities were provided at Wake Island, Kwajalein Island, and San Nicholas Island. The Wake and Kwajalein sites provided an extension for the Hawaii air-ground facilities. California had additional coverage provided by the San Nicholas installation.

## Network Operations

Time at the tracking station is generally divided into mission periods and nonmission periods. The mission period for Mercury comprised some 10 days prior to launch and the actual flight time. The nonmission period was the time between missions used for personnel training, equipment modification, testing, and checkout. The operations activities during the mission period are explained in the following paragraphs, with the MA–9 mission used as an example.

### Precountdown

The MA–9 precountdown period for all network stations was scheduled as follows:

F–7 day—Orbital mission simulation and reentry simulation
F–6 day—Orbital mission simulation and reentry simulation
F–5 day—Two reentry simulations
F–4 day—Detailed system tests
F–3 day—Equipment maintenance
F–2 day—Orbital mission simulation
F–1 day—Patching check and equipment maintenance

These various activities are described in the following paragraphs.

*Simulations.*—To the station, the simulations were full-dress rehearsals for the missions. With the entire network participating and all onstation systems in operation, authentic dry runs were conducted, complete with builtin emergency situations which had to be detected, analyzed, and acted upon in "real time" by the flight controllers and station personnel. Authenticity was gained by the use of taped inputs to the telemetry displays and events recorders and by the use of a communicator reading from a prepared script over the intercom loop that would ordinarily carry the real astronaut's voice. In addition to anticipated problems of spacecraft equipment malfunctions, the ground team had to cope with such remote possibilities as simulated heart attacks of the astronaut in flight.

Simulations would ordinarily cover launch and three orbital passes and might or might not cover reentry. Each simulation would take from 4½ to 6½ hours. Prior to MA–8, a full 18-orbital-pass mission was simulated in anticipation of MA–9 as a means of pointing out any major problem areas in personnel scheduling, sleeping, and eating plans.

*Detailed system tests.*—The detailed system tests (DST), mentioned earlier as being performed on F–4 day, were a group of standard procedures used to check and measure thoroughly the operational performance of each of the station subsystems. Since the same test was used for corresponding systems at all stations, and since results of previously run DST's were recorded, the current status of any subsystem could be easily evaluated by the DST performed just prior to the mission.

The DST procedures consisted of two parts: the instructions and the data sheets. Meter readings, voltage and current measurements, standing-wave ratios, and various other parameters were recorded on the data sheets which were returned to Goddard for analysis immediately after the mission. On the station, the cumulative results of the DST's were used in the determination of the station status, which was a factor in the decision to proceed with or delay the launch.

*Maintenance day.*—F–3 day and F–1 day were left open for last-minute maintenance details, particularly in correcting any equipment deficiencies detected during the DST's. Final briefings were also held to correct any procedural problems pointed up by the previous simulations.

### Network Countdown

The network countdown began 5 hours and 50 minutes prior to the scheduled launch. This time was devoted to computer and data flow checks, teletype checks, voice checks, and brief system tests. The Network Countdown document specifically scheduled each of these activities, and designated the stations and equip-

ment positions to which a particular operation was applicable. The brief system test was a shortened version of the DST and was designed to lend assurance that equipment performance had not significantly deteriorated since the DST was run 4 days previously. Whereas the DST may have taken 12 or more hours, most DST's could be performed in less than 2 hours.

The Network Countdown also contained the "plus-count," a scheduling of pertinent activities to be performed before acquisition of the spacecraft and during the pass.

### Flight Activities

After launch of the spacecraft, a time period of from about 5 minutes (at Bermuda) to 90 minutes (at Eglin) would elapse before the spacecraft passed over the station. The actual pass, the time from which the spacecraft appeared above the horizon until it was lost below the horizon, averaged about 7 minutes. Average time between passes was about 85 minutes. This time was devoted to equipment calibrations—setting up known levels and annotating the recorders so that later analysis would have known standards—and preparation for the next pass.

Prepass calibrations were begun 45 minutes before the start of the next pass. Twenty-five minutes prior to the pass the first acquisition message would be received. This was a teletype message sent from the control center advising the station of the time and coordinates at which it could expect to acquire the spacecraft. These figures were derived by the computers at Goddard based on the real-time radar data from the last station passed over by the spacecraft. The information permitted the acquisition and and radar operators to train their antennas to the spot where the spacecraft would first be "sighted." A second acquisition message was received 5 minutes prior to the spacecraft passage to communicate any inflight deviations during the intervening 20 minutes.

Acquisition would ordinarily take place within a few seconds of horizon time. Because of the wide beamwidth of the antenna used by the active acquisition aid, this system ordinarily was the first to acquire the target. At radar sites, the S-band and C-band radars would nonetheless search independently. At contact, all antennas were immediately slaved to the system which acquired first.

As the radar locked on target, it would then be set to track automatically, and, at operator discretion, it could be made the controlling system for the other antennas. At dual radar sites, data from the C-band radar—the most accurate of the two systems—was fed to the teletype for transmission to the computers at Goddard. If this radar lost track, data from the S-band radar were put on the line.

As soon as possible after the last pass over the station, the postlaunch instrumentation message was teletyped to the control center. It contained a tabulation of the times of acquisition and loss of signal for the various systems, the modes of operation, and a summary status report.

It was obvious that the length of the MA–9 mission would preclude the manning of all station equipments from launch to termination. The flight path was such, however, that all stations had periods when the spacecraft would not pass over them for three or more orbital passes.

*Documentation guides.*—Three documents provided the major guideline for station personnel activities during the pass. The Network Operations Directive 61–1, was produced jointly by MSC, GSFC, and DOD and it set forth the general operating procedures for all systems so that a standard action would be used in a given circumstance at any station in the network.

The second document, the Data Acquisition Plan, gave detailed instructions for recorder setups, pen assignments, patching arrangements, and plotboard assignments, and gave information for disposition of data records after the mission. A new Data Acquisition Plan was published prior to each launch. It was prepared by MSC with inputs from GSFC.

The third document was the Communications Operations Plan, prepared by GSFC. This was a detailed account of how the communications network was to function.

## Performance

The Mercury network, throughout all orbital flights of the Mercury spacecraft, has clearly demonstrated its capability to keep track of a manned spacecraft and remain in communica-

tion with the astronaut. These capabilities are the direct result of the many months of planning, instrumentation installation and checkout, training, and the highly efficient performance of the equipment and personnel at all network sites during the actual missions.

There were six orbital flights of the Mercury spacecraft, one unmanned (MA–4), one with a

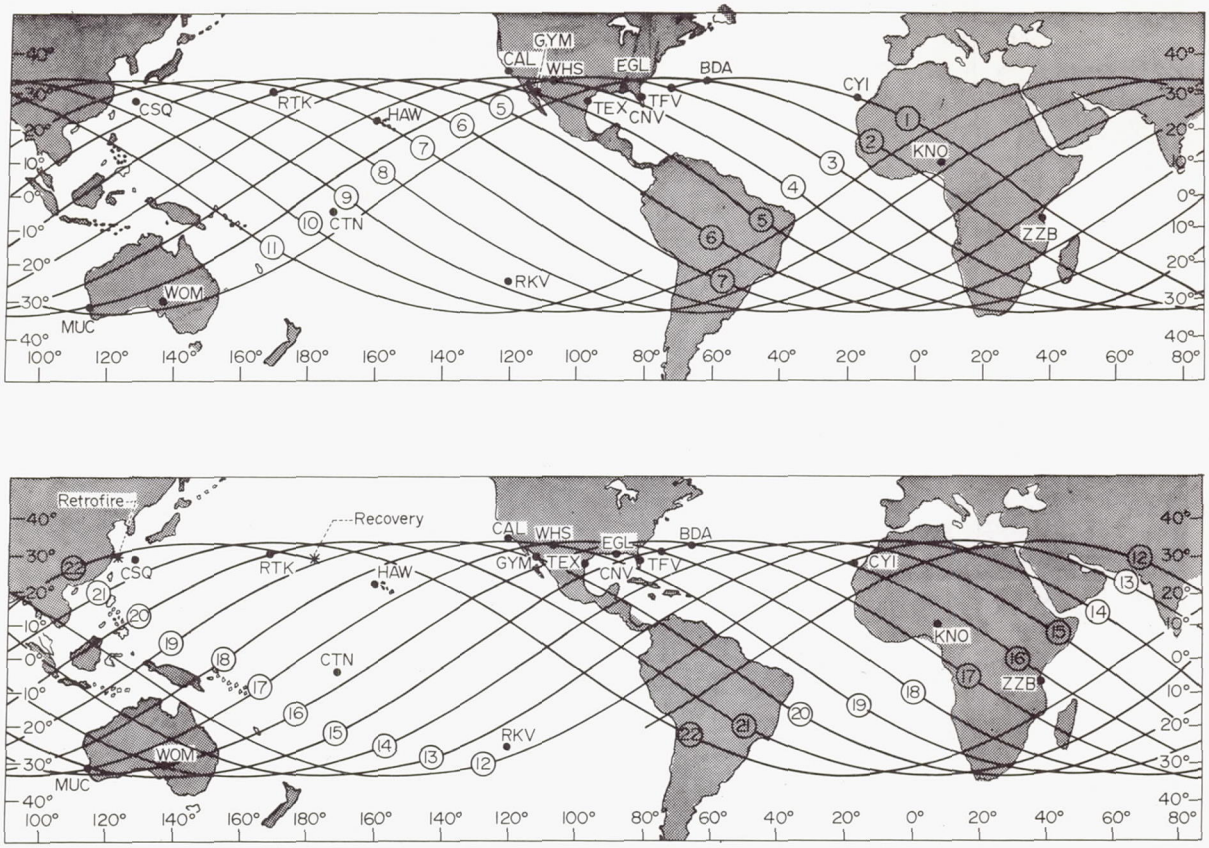



FIGURE 8–20.—MA–9 orbital charts.

chimpanzee aboard (MA–5), and four manned (MA–6 through MA–9). The network performance continually improved during these missions as more and more experience was gained. This progress was typified by the peak performance demonstrated during the last Mercury mission, MA–9. It lasted for nearly 22 orbital passes (fig. 8–20) with the spacecraft landing in the planned landing area near Midway Island in the Pacific Ocean. There were some minor equipment failures associated with the Mercury network, but they did not materially affect mission support or detract from the excellent performance demonstrated by the network throughout the flight.

A summary of network performance for the MA–9 mission is presented in the following paragraphs.

### Radar Tracking

During the countdown on May 14, 1963, the radar at Bermuda failed to pass the CADFISS slew tests. Digital data were intermittently of poor quality in both the azimuth and range channels. Efforts to locate the trouble were ineffective, and the quality of the data gradually decreased. At T–15 minutes, the range data error exceeded the tolerable limits, and at T–13 minutes the mission was postponed for 24 hours. Subsequent investigation revealed a faulty preamplifier in the azimuth digital-data channel and a faulty shift register in the range digital-data channel. The simultaneous failure of both components complicated the failure analysis.

On launch day there were no radar problems, and the C- and S-band beacon checks prior to

launch indicated no beacon problems. The network C-band radars tracked approximately 10 percent of the total mission time, which is 80 percent of the total time that the C-band beacon was turned on. The network S-band radars tracked 1.7 percent of the total mission time, which is 36 percent of the total time that the S-band beacon was turned on. The amount of radar data furnished to the Goddard computers was of sufficient quality and quantity to update the trajectories, and it was determined that the orbital parameters did not decay an appreciable amount. Initial tracking reports indicated that the C-band beacon was not as good as it had been on previous missions because of the heavier than usual modulation on the beacon replies. The heavy modulation experienced by the MCC and Bermuda radars during launch seemed to lessen as the mission progressed.

In addition to the normal Mercury Network radar sites, the following sites were used for the MA–9 mission: Ascension Island, East Island, Puerto Rico, and the radar ships Twin Falls Victory and Range Tracker.

#### Acquisition Aid

In general, the performance of the acquisition-aid systems at all stations was satisfactory and comparable to that of previous missions. Low-angle elevation tracking, below approximately 15°, was accomplished manually because of multipath conditions at most stations. The only major acquisition-aid problem experienced during the mission was on the Coastal Sentry Quebec, where failure of the elevation antenna drive system occurred prior to the 6th orbital pass. However, the antenna was positioned manually from the 6th through the 8th passes, and the malfunction in the drive system was corrected in time for acquisition in the 9th pass.

#### Computing

The MA–9 countdown began at midnight on May 14, 1963. The Goddard computer, equipment, interface, CADFISS, and trajectory confidence tests were all satisfactory. During the countdown, while using the "B" computer, some dropout was observed at the MCC. The high-speed output subchannel on the "B" computer communication channel was interchanged with the plotboard high-speed subchannel.

At the request of the Flight Dynamics Officer, the powered flight phase was supported with the "A" and "C" computers, then switched to the "A" and "B" computers during orbital flight. The "B" computer gave no indication of dropout during the rest of the mission. Liftoff occurred at 08:04:13 a.m. e.s.t.

The Atlantic Missile Range (AMR) I.P. 7094 and the General Electric-Burroughs guidance computers provided excellent data throughout the launch. A "go" decision was indicated by all three data sources.

In the orbital phase, during the periods when the spacecraft C- and S-band beacons were on, the tracking data received from the network sites were excellent. During the mission, spacecraft weight change data resulting from fuel and coolant-water usage were manually put into the computers.

The retrofire time recommended by the Goddard computers was 33:59:30 ground-elapsed time (g.e.t.), and retrofire was manually initiated at this time. After retrofire, the predicted landing point transmitted to the MCC from the Goddard computer was 27°22′ N. latitude and 176°29′ W. longitude. An attempt to refine this prediction with six frames of data acquired by the Range Tracker ship during blackout failed to yield a converged solution. The computed time of the blackout was from 34:08:16 to 34:22:30 g.e.t. The actual time of initial blackout was reported by the Range Tracker to be 34:08:17 g.e.t. The actual landing point was reported by the recovery ship to be 27°22.6′ N. latitude and 176°35.3′ W. longitude.

Although several minor computer problems were encountered and corrected throughout the flight, at no time during the mission did the computers fail to drive the digital displays and plotboards at the MCC. In addition, performance of the high-speed lines between Goddard and the MCC was excellent.

For the first time, CADFISS tests were conducted during the mission to determine the operational status of major equipment subsystems at network sites. These tests were considered necessary since mandatory equipment at many sites did not operate for prolonged periods of time when the spacecraft was out of range. All of these tests were successfully supported by the third Goddard computer while the other two

Goddard computers continued the operational support of the mission.

Two range ships, the Range Tracker and the Twin Falls Victory, were used to provide tracking data to the computers. The Range Tracker provided good tracking data during the 7th, 20th, and 21st orbital passes. During reentry the Range Tracker was poorly positioned with respect to the blackout zone and provided only six frames of data for this phase of reentry. An analysis of these data indicated a landing point which was about 3° or 180 nautical miles away from the correct landing point. Twin Falls Victory data readout was good on three passes.

#### Ground Telemetry System

The telemetry coverage for the mission was excellent. There were no major ground system failures, although some coverage was lost because of the manual switching procedure used onboard the spacecraft. In general, any deviation from nominal coverage can be attributed to spacecraft attitude or to the transmitters being turned off. The telemetry relay circuits from Antigua, California, Bermuda, and Ascension were satisfactory in all respects. During all passes over these stations when telemetry antennas were radiating, data were remoted to the MCC. During the third orbital pass, the telemetry was switched to the high-frequency link prior to the spacecraft's passing over Hawaii and remained on until it was over the California site, at which time telemetry was switched back to the low-frequency link. At all other times, the telemetry remained on low frequency. No telemetry system anomalies were noted during this period.

#### Air-to-Ground Voice Communications

The air-to-ground communications were of good quality. The UHF system was used as the primary communications system except for the scheduled HF checks. During periods of communication, UHF coverage varied only slightly from predicted acquisition and loss times because of the nominal orbital trajectory. As expected, air-to-ground communications could not be established during the communications blackout period. An Instrumentation Support Instruction was transmitted to the network outlining the use of the UHF squelch circuit as defined in the network documentation. A premission checkout and the mission results indicated that proper use of the squelch circuit eliminated background noise from open UHF receivers during periods of silence. This change also resulted in a reduction of noise level on the Goddard circuit during air-to-ground transmissions.

Relay aircraft in the Atlantic Ocean area reported good UHF reception from the spacecraft and good relay transmissions to MCC on the 2nd, 3rd, and 17th orbital passes. A relay attempt on the 16th pass was unsuccessful because of a severe thunderstorm in the vicinity of the relay aircraft. Communications from the MCC to the spacecraft through the relay aircraft were not attempted on the 2nd pass, and they were unsuccessful on the 3rd pass because the spacecraft had passed out of range. However, the relay communications were successful on the 7th pass. Ascension and Antigua Islands in the Atlantic were also available for relaying communications between the spacecraft and the MCC. Relay through Ascension was successfully accomplished for a period of approximately 6 minutes during the third orbital pass. The Antigua voice relay was not used during the mission.

In the Pacific Ocean area, communications were successfully relayed from Hawaii through Kwajalein and Wake Islands on passes 3 and 19, respectively. A voice-operated relay from the MCC through the Range Tracker was attempted on the 20th orbital pass. However, this attempt was unsuccessful because the transmission was made on the MCC-Hawaii remote air-ground position instead of the Goddard Conference Loop. This error apparently placed a 1700-cps tone on the circuit to the Range Tracker and resulted in keeping the automatic voice relay continuously closed; however, several transmissions from the astronaut were received in the MCC. Another attempt to use the relay on the 22nd pass was ineffective. As in the MA–8 mission, satisfactory communications were established in the primary landing area between the spacecraft and Hawaii by using relay aircraft.

#### Command System

The reader is referred to appendix F for a transcript of the MA–9 air-to-ground voice communications.

The command system for the MA–9 mission operated in a satisfactory manner, and the command control plan was followed very closely throughout the mission. Several malfunctions were noted at various sites, but command capability was never lost by any site during the time in which the spacecraft was passing over that site. The command carrier "on" indication from the Bermuda station to the MCC was delayed approximately 32 seconds on the first pass; however, it had no net effect on the mission since the onboard command receiver signal strength remained above the receiver threshold setting.

A total of 19 functions were transmitted from the command stations. All of these functions were received onboard the spacecraft with the exception of one telemetry "on" function from Muchea and the clock change from the Coastal Sentry Quebec. The telemetry "on" command from Muchea was not received because it was transmitted when the spacecraft was out of range of the 600-watt ground transmitter. The clock change from the Coastal Sentry Quebec was not received because the command tone was also sent before the spacecraft was within range of the ground transmitter.

The following ground-system malfunctions were experienced:

(1) The Rose Knot Victor had an intermittent problem in the beam power supply of the backup power amplifier. It was detected before lift-off and the equipment remained inoperative throughout the mission. The prime transmitter was used to support the mission.

(2) Guaymas had a failure in the filament transformer of the standby transmitter at 29:40:47 g.e.t. which damaged the power amplifier tube. The filament transformer and the power amplifier tube were both replaced and the equipment was operational by 32:05:47 g.e.t. The prime transmitter remained operational during this time.

(3) The Bermuda high-power transmitter came on with a 3.6-kw output but did not come up to full power. The station automatically switched to low power, 600 watts, at 00:06:31 g.e.t.

### Ground Communications

All regular, part-time, and alternate circuits of the network participated in the MA–9 mission. Critical coverage was continuously established on these circuits during preflight countdown until the end of the mission for Adelaide, Muchea, Honolulu, New York, Mercury Control Center, and GSFC. For other sites, critical coverage was dependent upon standby status (critical coverage being allowed to lapse when the station was on a standby basis.

Upon review of the SCAMA log for the mission, it is apparent that this phase of communications was quite reliable. The few instances of poor readability were mainly a result of the station operation techniques and excessive background noise inside and outside the station.

Communications during the mission were nearly perfect. Every communication patch performed properly when needed. As anticipated, outages occurred on a few occasions when a station did not have the spacecraft "in view" or during otherwise unimportant communications periods.

Average total message delays during MA–9 approximated 2 minutes, compared with 3 minutes and 15 seconds for MA–8. This difference can be accounted for by the heavier traffic concentration of MA–8.

The MA–9 mission occurred during a period of high solar activity. Unlike MA–8, however, there were no geomagnetic disturbances and the propagation conditions were favorable.

### Timing

The timing system performed satisfactorily at all stations except California. On passes 3, 4, 5, 16, 17, and 18, the serial decimal timing was in error in tens-of-seconds readout. The problem was corrected after pass 18 by replacing all tubes in the timing counter units and adjusting the phanastron in the time-comparison unit. During pass 20, the timing system was again defective since it indicated 21 hours rather than 20 hours.

707–056 O—63——11

## References


1. Staff of NASA Manned Spacecraft Center: *Results of the First United States Orbital Space Flight, February 20, 1962.* Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
2. Staff of NASA Manned Spacecraft Center: *Results of the Second United States Orbital Space Flight, May 24, 1962.* NASA SP–6, Supt. Doc., U.S. Government Printing Office (Washington, D.C.).

# 9. OPERATIONAL SUPPORT FROM THE DEPARTMENT OF DEFENSE

By Major General Leighton I. Davis, *U.S. Air Force, Department of Defense Representative for Mercury Support Operations*


## Summary

The Mercury–Atlas 9 mission marked the successful conclusion of the nation's first manned space flight program to which extensive operational support had been provided by the Department of Defense. This support covers many assets uniquely available within the broad scope of this nation's military structure and includes such areas as early wind-tunnel studies, astronaut training facilities, parachute development, launch vehicles and launch operations, aeromedical assistance crews, network facilities, recovery forces, and public information.

Early in the program a need was recognized for a more precise planning and control of the many areas of DOD support to the National Aeronautics and Space Administration. A Department of Defense Representative for Mercury Support Operations was designated by the Secretary of Defense and was the sole point-of-contact within the DOD for coordinating all NASA requirements with DOD resources. A coordinating organization, the Mercury Support Planning Office, was established to administer the plans, policies, and directives of the DOD Representative.

Both the Redstone and Atlas launch vehicles developed by the DOD for other programs were modified and together with launch operations provided support for the Mercury flight program. Military facilities and persons associated with tracking and telemetry stations within the DOD complex were made available to complete the Mercury Worldwide Network. By far the largest DOD support effort in terms of people, was the level of recovery forces deployed for the various Mercury missions. This manpower level was approximately 14,000 people for the manned orbital missions. For those missions where an occupant was included in the spacecraft, DOD medical teams were deployed to provide assistance to NASA medical specialists. The global DOD communications complex was activated for use during Mercury missions to lend support in a variety of areas where high-speed information flow was required. This communications complex, in addition to facilities of the Mercury Worldwide Network, was especially valuable in coordinating the deployment and operation of the recovery forces for an orbital mission. The DOD also supported the NASA in disseminating and controlling Mercury mission information for public consumption through its public information organization.

Providing support to Mercury flights has contributed greatly to the Department of Defense's knowledge and experience in areas of launch, network, recovery, communications, and medical space operations. Future space-flight operations can be effectively supported by applying the experience and procedures derived during Project Mercury.


## Introduction

Throughout the Mercury Project, the Department of Defense (DOD) provided valuable and timely support in critical operational phases of the project. As the project progressed and the scope of its activities increased, a need for a centralized coordinating agency within the DOD was recognized. The person in charge of this agency was designated the DOD Representative who had the sole responsibility of coordinating the resources of the various military organizations to satisfy the project requirements of the National Aeronautics and Space Administration. In this regard the DOD Representative was the primary point-of-contact for the NASA Operations Director in conjunction with specific requests for Mercury support.

Prior to the designation of a DOD Representative for Mercury support operations, operational support for the project was handled on an official but somewhat informal basis. The intent of this paper is to describe the operational support that was provided after the designation in 1959 of a DOD Representative for Mercury support operations. This designation also provided NASA with a single point-of-contact for the submission of their DOD support needs.

Early in the Mercury Project wind tunnel facilities such as the Arnold Engineering and Development Center, Tullahoma, and the crew training devices such as the Centrifuge at Johnsville, Pa., were also made available; however, these support areas will not be discussed. The support areas which are discussed comprise launch vehicles and operations, worldwide tracking, recovery, communications, aeromedical, and public information. These areas are discussed separately as they pertain to Mercury-Redstone and Mercury-Atlas mission activities and are followed by a summary of DOD support provided for each specific mission. Although the DOD provided launch, range, and recovery support for the first Atlas launch, named Big Joe, and for the Little Joe spacecraft development flights, these are not presented. The Big Joe flight was conducted to provide early aerodynamic and thermodynamic data by reentering a boilerplate spacecraft. A greater emphasis is placed on describing the gradual build up of operational support from the relatively simple ballistic flights, requiring assistance primarily in the area designated the Atlantic Missile Range, to the worldwide orbital missions requiring DOD medical, network, and recovery forces stationed around the globe.

This paper is intended only as a summary of the concepts and techniques employed in the various support areas relating to the Department of Defense. The Aeromedical Activities, Network Development and Performance, Recovery, Redstone Development and Performance, and Atlas Development and Performance papers should be consulted for greater detail in the operational aspects of these subjects.

## Planning and Organization

The National Aeronautics and Space Administration had sole responsibility for conducting the Mercury project. The NASA Operations Director was designated as the single point-of-contact with the Department of Defense. The talents, resources, and facilities of the Department of Defense were used to assist NASA in attaining the overall objectives of the project. The Secretary of Defense approved DOD support of Project Mercury in areas of launch, network, recovery and bioastronautics.

The Commander, Atlantic Missile Range Test Center (AFMTC), was designated as the Department of Defense Representative for Project Mercury support operations by the Secretary of Defense and was made responsible to coordinate the efforts of the many DOD elements involved and to provide a single point-of-contact for NASA for the Mercury Project. The DOD Representative was authorized such staff as he might need to accomplish his duties and was required to make maximum use of existing DOD organizations and procedures. Broad plans of DOD support for Project Mercury were developed by the DOD Representative and published in an Overall Plan on January 15, 1960.

The Mercury Support Planning Office, consisting of representatives from the major participants in DOD support of Project Mercury, was created to administer the plans and policies of the DOD Representative. This office coordinated NASA's support requirements for Mercury with the DOD elements to insure that needed support in the form of talent, facilities, organization and other resources, was timely and sufficient to the extent compatible with DOD's primary defense mission. The Mercury Support Planning Office was the final coordinating staff office for the DOD Representative in all matters relating to DOD support of Project Mercury operations.

Department of Defense support was originally divided into two stages: preoperational and operational. The operational stage included launch through recovery phases and the preoperational stage included all other times during which DOD supported Project Mercury. During each of these stages, control of DOD support differed, and a separate functional organization was required. In the preoperational stage, the DOD Representative had responsibility for coordinating the action of DOD

forces in Project Mercury activities. In the operational stage, full decision-making responsibility was exercised by the NASA Operations Director. In either stage, additional guidance was provided by direct contact between the DOD Representative and the NASA.

These planning, coordination and control procedures, set up in the early days of Project Mercury, remained basically unchanged until the end of the seventh Mercury-Atlas mission (MA–7). After MA–7, it was decided to amend the charter of the DOD Representative to insure a tighter control of the diverse DOD elements during mission operations, because of the expanding scope of the program, the need for a change in operational procedures and realinement of recovery communications. As a result, the duties and responsibilities of the DOD Representative were revised in June 1962. Significant changes were incorporated into the revised terms of reference for the DOD Representative which established two phases of operational support: the coordinating phase and the operational control phase which, at times, ran concurrently. The coordinating phase was that time during which plans were developed and resources arranged to support future operations. This phase was continuous and included training and simulation exercises preparatory to flight operations. The operational control phase included the launch through recovery aspects of the mission and began at 24 hours before the scheduled launch at which time the DOD Representative assumed operational control of the DOD forces, assets, and facilities used for support of Mercury operations. This phase terminated at the time the spacecraft and its occupant were recovered and turned over to NASA officials.

To provide for the centralization of overall operational control of the global recovery forces, the DOD Representative established the DOD Mercury Recovery Control Center at Cape Canaveral. Another method used by the DOD Representative for exercising operational control of the support forces was the publication of operations orders and directives prior to each mission. These orders proved to be an effective means for conducting these missions and contained a more detailed description of the procedures by which operational control would be exercised by the DOD Representative. Based on these orders, the supporting commanders prepared their individual directives for the control of their assigned forces.

### Documentation

Several methods were used by the DOD Representative to evaluate DOD performance during the Mercury Project. Monthly status reports were submitted by the DOD Representative to the Secretary of Defense and Annual Reports summarized calendar year operations. Postmission reviews and preoperational conferences were held by the DOD Representative and attended by representatives from NASA, the National Ranges and DOD support forces.

Prior to each mission, the DOD Representative received readiness reports from the support forces and kept NASA informed as to the DOD's ability to support the mission. DOD forces were kept apprised of countdown status, lift-off time, flight progress, and landing information during an operation.

To consolidate and standardize the administrative and operational procedures for the DOD National Ranges, Operations Plan 60–1 was published in 1960. The procedures proved so effective for the early Mercury flights that a joint DOD/NASA document, Network Operations Directive 61–1, was published with a detailed description of the manner in which the DOD, NASA and the Australian Weapons Research Establishment (WRE) facilities would operate as an integrated global network in support of Project Mercury. The documentation flow which transferred information between NASA and DOD started with the NASA Program Requirements Document which requested specific items of support from the ranges. The ranges, in turn, replied with a Program Support Plan which specified how they would meet NASA's requirements.

### Launch Support

Launch operations for Project Mercury were conducted at the Cape Canaveral Missile Test Annex of the Atlantic Missile Range. The Redstone vehicles were launched by NASA Marshall Space Flight Center assisted by members of the Army Ballistic Missile Agency. Other DOD participation in the Redstone launches was limited to standard launch complex and

instrumentation support normally provided to missile programs by the AMR.

The DOD role in Atlas launches was extended to include the Atlas D launch vehicle, guidance system, and launch complex, and was provided by the Space Systems Division (SSD) of the Air Force Systems Command (AFSC). The 6555th Aerospace Test Wing of SSD located at Patrick AFB was given the responsibility for final installation, prelaunch checkouts, and actual launch of the Atlas launch vehicle to insert the Mercury spacecraft into a proper orbit.

### Network Support

The mission of the Mercury Worldwide Network was to enable flight control people to monitor, by electronic means, the status and performance of the spacecraft, its systems, and its occupant and to communicate with the pilot. To accomplish this mission, NASA, with the assistance of the DOD, implemented a global tracking and telemetry network. This network required the use of certain existing DOD stations as well as the construction of additional facilities. As originally planned, the network consisted of 14 land-based stations, two DOD tracking ships, and a communications center.

A listing of the network stations is as follows:

| *Station number* | *Station name* | *Operating agency* |
|---|---|---|
| 1 | Cape Canaveral | AMR |
| | Grand Bahama | AMR |
| | Grand Turk | AMR |
| 2 | Bermuda | NASA |
| 3 | Rose Knot | AMR |
| 4 | Canary Island | AMR |
| 5 | Kano | NASA |
| 6 | Zanzibar | NASA |
| 7 | Coastal Sentry | AMR |
| 8 | Muchea | WRE |
| 9 | Woomera | WRE |
| 10 | (Deleted) | |
| 11 | Canton Island | PMR |
| 12 | Hawaii | PMR |
| 13 | Pt. Arguello | PMR |
| 14 | Guaymas | NASA |
| 15 | White Sands | WSMR |
| 16 | Corpus Christi | WSMR |
| 17 | Eglin | APGC |

The network was later modified on a mission-to-mission basis by other DOD facilities, including additional stations of the Atlantic Missile Range and two radar tracking ships. The DOD Communications Center was replaced by the NASA Communications and Computing Center at the Goddard Space Flight Center (GSFC) and some Mercury stations became identified by names more descriptive of their actual location.

During Mercury missions, the entire network was under operational control of the DOD Representative's network commander, assisted by the network status monitor, who advised the NASA Operations Director on the status of the network to perform its mission. Upon termination of the mission, operational control of the stations reverted to the respective range commanders or the NASA, as appropriate. After the network had been established, NASA provided the technical planning, augmentation, and modification of the network to complement the DOD operational control.

Instrumentation for the initial Mercury flights involved only the facilities of the AMR. The entire network, except for the Coastal Sentry, was first called up for support of MA–3.

The first time a Mercury network instrumented ship was used in support of a Mercury mission was during MR–3. The Coastal Sentry ship was located in the landing area for telemetry and communications between the spacecraft and the ground.

For the second manned flight, MR–4, the AMR Rose Knot ship, was deployed in the landing area. It was during MA–4 that most of the network stations had their first opportunity to attempt radar track. In general, radar track from the stations was poor and the Bermuda, White Sands, and Woomera data were not usable at Goddard. A postflight review was held at AMR and was attended by representatives from all of the radar sites. It was learned from this review that the antenna patterns for both the C- and S-band beacons were not good because of deep nulls in the antenna patterns. A decision was made to install an antenna pattern-phase shifting device on the spacecraft for the next mission. This device introduced a phase delay of 400 cycles per second to shift the antenna pattern and effectively smear over the deep nulls.

The installation of the phase shifter on the C-band antenna system for MA–5 proved successful. During the MA–5 postmission review, indications were that the radar coverage was

much improved. This improvement was the result of the use of the phase shifter, the intensive training received by the radar operators between missions, and by the use of a radar controller on the handover net.

During the MA–7 flight, several stations reported amplitude modulation by the phase shifter on the C-band beacon; however, reentry data were smoother than on previous missions. The two relay aircraft obtained SARAH beacon bearings on the spacecraft and confirmed its location prior to sighting.

Failure of the magnetron driver unit on the Canary Islands Verlort radar caused a 15-minute hold in the MA–8 countdown. Some communications problems were encountered during periods of poor propagation conditions and aircraft relay was unsuccessful because the distance between spacecraft and aircraft was too great.

The launch for the Mercury-Atlas 9 (MA–9) mission was the first mission rescheduled because of network difficulties. Bermuda's C-band radar had unacceptable range data errors because of a faulty shift register in the range digital data channel and a faulty preamplifier in the azimuth digital data channel.

The network for MA–9 was augmented by the addition of the Twin Falls Victory Ship (AMR), the USNS Range Tracker (PMR), Antigua Island, Ascension Island, East Island, Wake Island, and Kwajalein Island.

Relay aircraft were equipped with high gain antennas and the spacecraft-to-ground voice relay was successful. Voice relay was also accomplished through Ascension, Wake, and Kwajalein. Radar aircraft of the Air Defense Command, used as part of the network for the first time, obtained a good skin track of the spacecraft during reentry, including blackout, and were able to obtain some contact during orbit. For the first time, stations were allowed to go on standby status during the orbital phase, and computer and data flow tests were conducted to confirm their return to operational status.

## Recovery Support

During Project Mercury the DOD contribution to planned and contingency recovery operations expanded considerably. Starting with a concentration of all recovery efforts about a single planned landing area, recovery support multiplied until the DOD was supporting 32 planned landing areas and 51 contingency landing areas for the final Mercury mission. For MR–1A, the first unmanned ballistic flight, the recovery support forces consisted of 8 ships and 15 aircraft all located within 1,500 nautical miles of Cape Canaveral. Recovery support for the final MA–9 mission consisted of 28 ships and 171 aircraft.

### Mercury-Redstone Series

The Mercury-Redstone series of four flights which required recovery support took place during the period December 1960 to July 1961. These missions all involved ballistic trajectory flights, with the primary planned landing area located directly downrange northeast of Grand Bahama Island. Naval ships and aircraft formed the recovery task force and were assigned stations within the designated recovery areas. Aircraft units from the Air Rescue Service (ARS) and the Air Force Missile Test Center (AFMTC) assisted the surface recovery forces. Contingency recovery commanders were designated and units of their commands were pre-positioned along the ballistic track to insure readiness should a contingency recovery situation have occurred.

### Mercury-Atlas Series

Mercury-Atlas missions MA–3 to MA–9 were all planned as orbital flights varying from one orbital pass to the extensive 1-day, 22-orbit mission which concluded the Mercury program.

With the advancement from ballistic to orbital flight, the support provided by elements of the DOD substantially increased. No longer was it sufficient to consider only a downrange flight path, but now it was necessary to view the entire earth-circling orbital paths as potential contingency recovery operation areas. Although the number of planned landing areas increased from 1 to 32, the greatest expansion of DOD recovery effort occurred in the area of contingency recovery operations. The support of contingency recovery landing areas was primarily borne by aircraft, and in many instances by the same aircraft used in support of planned landing areas. The number of aircraft directly participating in recovery operations for this series increased from 22 located along the AMR

ballistic track to 171 located at 30 land-based sites and onboard two aircraft carriers.

The unmanned flight of MA–3 was the first planned one orbital pass mission, but failure in the launch vehicle resulted in its destruction by the Range Safety Officer. The spacecraft escape system worked perfectly and the spacecraft was retrieved by a launch-site recovery-force helicopter, 200 yards off shore. This was the only time during the program that the launch-site recovery forces had to put into practice the many hours of training for just such an emergency.

Because of extensive slippages in the original scheduled dates for the orbital missions, two separate and distinct recovery-force deployments were required. The DOD recovery forces in support of these missions adjusted and substituted units as necessary to meet normal military commitments during the periods between recovery deployments. Despite these reorganizations, all recovery elements and units were ready and effectively performed their recovery missions.

The MA–7 mission of Astronaut Lieutenant Commander Carpenter, USN, terminated after a three-orbital flight with a 250 nautical mile overshoot of the primary landing area. Recovery was effected, however, about 3 hours after landing. A postmission review of this flight revealed the need for a change in recovery communications and operational procedures. This review led to the establishment of a DOD Mercury Recovery Control Center (MRCC) jointly staffed by Commander Cruiser-Destroyer Flotilla Four (CTF-140) and his deputy, Commander Air Rescue Service, who performed the recovery mission for the DOD representative. Furthermore, recovery communications equipment and procedures were changed for future missions so as to provide a more tightly controlled recovery organization capable of quick response to changing situations.

The last two missions of the Mercury Project, MA–8 and MA–9, constituted a culmination of all the lessons learned in previous missions, and reflected the flexibility of the recovery forces when the primary planned landing area was relocated from the Atlantic to the Pacific Ocean. The final flight had the greatest number of recovery forces providing support and required the closest coordination of effort. The Pacific recovery force trained intensively in preparation for these missions, and the smoothness with which the two operations were conducted reflected their efforts and refined procedures. In both flights the manned spacecraft landed within 4½ miles of the primary recovery ship and was recovered and on board within 45 minutes in each case.

Recovery forces supporting MA–8 were deployed with 19 surface units in the Atlantic and 7 in the Pacific. A total of 134 aircraft provided the planned and contingency recovery support for this mission. For MA–9, surface support forces in the planned landing areas numbered 15 ships in the Atlantic and 11 in the Pacific. Air support was provided by aircraft from the Army, Navy, Air Force, Marine Corps, and the U.S. Coast Guard. Commander, Middle East Force, provided a contingency surface recovery force of two ships for the north Indian Ocean areas.

## Aeromedical Support

To fulfill the objectives of Project Mercury, the NASA requested the Department of Defense to provide certain medical support. The purpose of this support was to assure thorough on-scene medical care and a prompt and complete assessment of the astronaut's postflight condition.

On December 1, 1959, the Department of Defense Representative for Project Mercury Support Operations designated the Staff Surgeon, AFMTC, as his Assistant for Bioastronautics. The principal function of the Assistant was to plan, organize, and deploy worldwide medical support for Mercury flight operations in response to NASA medical requirements.

The Department of Defense provided medical support in the categories of administration, people, training, facilities, and equipment. The extent of this support is discussed to show the magnitude of such support.

### Administrative Support

Administrative support included selection and deployment of medical resources and facilities and the formulation of medical support plans. The scope of this support included the following:

(1) Development of medical plans and programs.

(2) Acquisition, siting, and making operationally ready, the required medical facilities.

(3) Requisition, preparation, and deployment of all needed medical equipment.

(4) The preparation of plans to provide blood for an injured astronaut and procedures in case of non-survival of an astronaut.

(5) Medical staffing of a Forward Medical Station, an Operational Support Unit, and launch site recovery forces.

(6) Deployment of people and equipment to fleet recovery units.

(7) Establishment of specialty teams and alerting of specific DOD hospitals.

In addition, administrative actions were taken to procure medical specialists from Australia and the Public Health Service to support each mission. Arrangements were made for immunizations, distribution of publications to recovery medical forces, and training programs.

#### Training

For the later manned missions, 84 medical officers were trained by the AFMTC in June 1960 and in April 1963, 23 DOD medical officers were trained specifically for MA–9 by NASA.

#### People

During the program 233 medically trained people were made available by the DOD in support of Project Mercury flight operations. These people served in the following areas:

(1) As aeromedical monitors. The monitors were assigned to Mercury network tracking stations. Their functions were to monitor, using telemetry displays, the physiological condition of the astronaut.

(2) At Cape Canaveral, to provide emergency surgical support in the event of a launch site incident or disaster.

(3) On recovery vessels, to provide immediate on-scene medical assistance in the event of a medical emergency during recovery operations.

(4) At advanced medical units in high probability landing areas at Grand Bahama Island and Grand Turk Island.

(5) In the Bioastronautic Holding Facility in Hangar "S", Cape Canaveral, to assist in preflight preparations.

(6) A dietitian and food service supervisor were provided in the astronauts' dining facility to prepare and serve prescribed diets to the flight astronaut and his backup.

#### Facilities

The following medical facilities were provided:

(1) Cape Canaveral: Two blockhouses were modified to provide a forward Medical Station, a Medical Command Post, a Medical Communications Center, an astronauts' diet kitchen and dining room, and a ready room for the Medical Specialty Team.

(2) Downrange: Two prefabricated surgical hospitals and medical debriefing units were erected at Grand Bahama Island and Grand Turk Island.

(3) The Wilford Hall USAF Hospital, Lackland AFB, Texas; the US Navy Hospital, Portsmouth, Virginia; the Walter Reed Army Hospital, Washington, D.C.; the Tripler General Hospital, Honolulu, Hawaii; were designated as specialty team hospitals. Seven other DOD hospitals were alerted in high probability landing areas, to support the astronaut if needed.

Senior medical officers from the three armed services established the medical equipment needs in support of Project Mercury. The medical supplies and equipment were provided to NASA on a loan basis and will be available for support of future manned space flights.

The DOD medical participation in Project Mercury has been mutually beneficial in that the NASA received support otherwise unavailable to them and the Department of Defense medical services gained extensive experience in medical support operations. These trained experienced people represent a core of technically competent specialists to support future manned space programs.

#### Communications

The termination of Project Mercury was also the termination of an extensive communications complex used by the Department of Defense forces in support of this NASA project. This complex started with the early Mercury ballistic missile communications limited to that of radar

and telemetry data needed within the confines of the Atlantic Missile Range (AMR).

As the project progressed to the orbital flights, communications grew in complexity to a point which involved the resources of the national ranges, Defense Communications Agency, and the equipment and facilities available to the separate commands, commercial agencies, and foreign governments.

Programs were initiated to provide communications that were uniquely required by the Mercury mission. Some of the equipment resulting from these programs was adopted by NASA for incorporation into future facilities support.

As Mercury missions advanced from unmanned suborbital to manned orbital flights, it became necessary for the DOD representative's staff to have communications specialists immediately available to assist in the overall DOD communications support as well as to participate actively in the operational phase of the missions. Beginning with the MA–7 mission, the function of the Communications Coordinator was performed for the DOD Representative by the Chief, Range Support Communications Division, AFMTC, assisted by other communications specialists in the AFMTC organization. The value of this group was fully realized during the course of the MA–9 mission. For this mission the most complex communications system employed in the support of the national space effort was implemented. From 48 hours before lift-off through test termination, this group of communicators supervised and maintained constant surveillance of the worldwide communications systems insuring that the best possible support and performance was afforded this Mercury mission.

#### Network Support

Communications for the Mercury suborbital flights consisted basically of the following:

(1) Launch pad intercommunications systems with associated circuitry to other Cape Canaveral instrumentation areas, such as command control, telemetry, radar, and central control. These systems were interfaced with those provided by NASA within the Mercury Control Center for internal communications.

(2) Voice, teletype, data, and timing circuits to Grand Bahama and Grand Turk Island tracking sites through the use of the AMR submarine cable.

(3) Ultra-high frequency (UHF) and high frequency (HF) communications between the spacecraft and ground with equipment provided by NASA and operated by the AMR at Cape Canaveral, Grand Bahama, and Grand Turk.

Additional communications support for the first manned suborbital flight consisted of a basic teletype and voice plan to provide for the passing of traffic to a recovery force consisting of 10 surface vessels and 11 aircraft in the Atlantic area. Teletype circuits connected the Mercury Recovery Control Center (MRCC) at Cape Canaveral to the three service communications centers, Andrews AFB, Ft. Detrick, and Cheltenham, in the Washington complex; the AMR submarine cable connected the MRCC with the recovery forces in Puerto Rico; and simple high-frequency single sideband (HF/SSB) voice communications connected the MRCC to the recovery ships and aircraft.

As the missions progressed into orbital flights, the NASA tracking network could not meet the need for expanded global tracking and communications requirements. The DOD augmented the existing NASA network by providing coverage at such stations as Antigua, Ascension, Pretoria, Kwajalein, Wake Island, and San Nicholas Island. DOD also provided range ships and aircraft specially configured for spacecraft voice relay.

During MA–8 and MA–9 the DOD provided communications support for the xenon flashing-light experiment being conducted at Durban, South Africa, by routing communications through the AMR station at Pretoria, South Africa.

The DOD Interrange tie line connecting Pt. Arguello, White Sands Missile Range, Eglin Air Force Base, and Cape Canaveral was widely used during the Mercury mission for radar handover and for intersite coordination. The value of this circuit was realized by both NASA and DOD elements for radar control. Beginning with the MA–6 and subsequent missions, modifications were made to include the sites at Guaymas, Mexico, and Corpus Christi, Texas. The line was extended to the Hawaii tracking site for MA–8 and MA–9.

To overcome problems associated with spacecraft-to-ground communications especially during the reentry period, the DOD initiated a developmental program on the use of airborne platforms as automatic relay stations. Special C–130 aircraft were configured with equipment capable of the receipt and automatic retransmission of the modes of communications, HF/UHF, available from the spacecraft or ground stations. Included in the program were various patterns by which the aircraft would fly so as to provide the best coverage and relay conditions. During MA–8 and MA–9 this system was also incorporated aboard the telemetry aircraft operated by the PMR in the Pacific area.

Shortly after MA–8, the AMR developed a technique for the relay of telemetry data by way of single-sideband radio. This system was successfully demonstrated in November 1962 from AMR stations Antigua and Ascension Islands to Cape Canaveral involving distances of 1,200 to 4,400 miles, respectively.

The system was offered to the NASA for use during MA–9 as a means of relaying real-time aeromedical data. The NASA accepted this proposal and the system performed successfully.

#### Recovery Support

In addition to the basic teletype and voice plan for passing communications traffic to the recovery force deployed in the Atlantic, provisions were also made for the handling of classified traffic by the installation of a secure teletype circuit between Patrick AFB and Cape Canaveral. The AMR submarine cable was used to interconnect the MRCC at Cape Canaveral with the recovery forces in Puerto Rico. High-frequency single-sideband (HF/SSB) voice communications were used between the recovery ships and aircraft in the Atlantic and MRCC.

For the MA–9 mission communications were needed to support 28 surface vessels, 171 aircraft, and various Recovery Control Centers and contingency forces deployed around the world. To tie this vast complex into an effective communications network, the communications resources of the DOD, with its inherent capability to interconnect with other governmental and commercial systems, were available to the DOD Representative's communications staff for support of MA–9.

The hub of the DOD recovery communications effort was the Mercury Control Center at Cape Canaveral. As missions progressed from suborbital to full orbital flights, the center was modified from one of limited communications support to an extensive and complex system which supported the 22-orbital flight (MA–9). This Center was designed to provide for the receipt of status information from worldwide deployed forces and for the passing of directions to the task force commanders. Desks were replaced by operational-type consoles equipped with communications systems capable of providing direct communications between the deployed forces and individuals on the recovery staff. Visual display equipment was provided for the rapid dissemination of information, as needed, within the MRCC and intercommunications links were installed for coordination between DOD and NASA elements.

#### General Support

As originally planned, the Mercury network communications system did not provide voice communications to network stations having an HF link connecting them with the Goddard Space Flight Center. In order to maintain voice communications with AMR range vessels operating under their control, the AMR established a voice circuit to two range vessels by using the unused sideband of the NASA SSB teletype circuit. This method of operation, commonly in use though not applied to the Mercury network, proved exceptionally useful to the flight controllers during early missions. This method of operation was extended to other Mercury stations so that during MA–9 voice communications were available to all sites.

Prior to MA–9, teletype communications from the Mercury Recovery Control Center were routed to the three military services communications stations in the Washington area complex. The basic service, although satisfactory, created delays when it became necessary to provide alternate routing or to correct technical difficulties and was also cumbersome in effecting coordination during the course of the mission. For MA–9, a plan was created which routed all teletype communications for the recovery forces through one station, Army East Coast Relay

Station at Ft. Detrick, for further dissemination by automatic means to the final destination. This new system proved very effective during MA–9 by providing a single point of contact for coordination purposes, a reduction of circuitry between Cape Canaveral and Washington, D.C., and an ability to react quickly to alternate routine requirements.

The Area Frequency Coordinator at AFMTC was given the responsibility for providing procedures and controls necessary to insure that the 11 spacecraft frequencies were protected from harmful interference. Critical times were established as being from 6 hours before lift-off through mission termination. The frequency protection plan, as developed, was applicable throughout a belt extending some 700 miles north and south of the predicted orbital paths. To provide the control agencies with timely information on implementation and termination of frequency protection, some 87 addressees were contacted by use of Address Indicator Group teletype messages. In addition to these actions, it was necessary during the course of Project Mercury to coordinate the assignment and use of 171 HF frequencies. Throughout the Mercury program a total of 43 cases of electronic radiation interference was reported and satisfactorily resolved or alleviated.

### Public Information

Department of Defense support of the NASA public information effort on Project Mercury began with logistic support of news media covering the early launches. A press site which offered a direct view of the Redstone launch complex was built near the Mercury Control Center for the flights of Astronaut Commander Shepard, USN, and Astronaut Major Grissom, USAF (MR–3 and MR–4, respectively). A new, improved press site was constructed near the Cape Canaveral landing strip, near the Atlas launch complex, for the orbital flights.

Logistic support of the news media covering the Mercury activities developed into a general pattern with the greatest amount of support required at Cape Canaveral. The number of accredited news media representatives covering the flights increased with each launch until more than 700 covered the MA–9 flight. Support included transportation, escorts, communications lines (525 pairs of telephone lines and six wideband video lines from the Cape press site), shelter, and public-address systems. AFMTC had a full-time representative at the NASA news media center; and for MA–8 and MA–9, a DOD information officer was on duty at the Pacific News Center in Honolulu.

For coverage of recovery operations, news media representatives were positioned with DOD forces in the primary landing areas and communications channels were furnished so that real-time reporting was possible. Excellent cooperation was received from all DOD agencies in the preparation of information material and in the support of news media people by DOD forces.

After MA–8 and MA–9, NASA Headquarters convened in a meeting of the press pool representatives from all news media to critique the information aspects of the flights. The reports of the media personnel indicated that the logistic support furnished by DOD was sufficient and timely.

### Review of Mercury Missions

The Department of Defense support discussed here is limited to that provided for the Mercury-Redstone (MR) missions and nine Mercury-Atlas (MA) missions during the Mercury Project. DOD support in the early phases of the Mercury Project was primarily in the areas of launch and network. As the project developed and missions became more complex in scope and objectives, DOD support expanded into the additional areas of recovery, communications and bioastronautics. The scope of this support, in terms of people, aircraft, and ships for the manned orbital flights is shown in tables 9–I and 9–II. A brief summary of each mission with regard to DOD support follows.

The first Mercury-Atlas vehicle (MA–1) was launched on July 29, 1960. The spacecraft was unmanned and was intended to land northeast of Antigua Island in the West Indies. Standard AMR tracking and data acquisition equipment was available and the recovery support consisted of units from the Atlantic Fleet (CINCLANT), Air Rescue Service (ARS), and AMR forces deployed as a task force. A structural failure occurred approxmiately 1

*Table 9–I.—DOD Support for Project Mercury Manned Orbital Missions*

| Organization | People Activity | MA–6 | MA–7 | MA–8 | MA–9 |
|---|---|---|---|---|---|
| Commander in chief, Atlantic Fleet | Recovery forces in Atlantic | 15, 000 | 10, 000 | 9, 000 | 6, 750 |
| Commander in chief, Pacific Fleet | Recovery forces in Pacific | 0 | 0 | 5, 000 | 6, 700 |
| Atlantic Missile Range | Range support, three tracking stations, safety, telemetry aircraft, radar ships. | 1, 300 | 1, 250 | 1, 250 | 6, 700 |
| Base Support Division/Space Systems Division. | Booster, guidance, pad (Canaveral/West Coast) | 500 | 480 | 455 | 430 |
| European Command | Contingency recovery forces in Africa | 215 | 265 | 215 | 300 |
| Pacific Missile Range | Three tracking stations, telemetry aircraft, radar ship | 195 | 165 | 310 | 345 |
| Air Rescue Service | Contingency recovery inland area and Atlantic | 160 | 210 | 210 | 485 |
| Bioastronautics | Support of medical operations, Air Force, Army, Navy | 160 | 130 | 95 | 100 |
| White Sands Missile Range | 2 tracking stations | 80 | 80 | 85 | 75 |
| Air Proving Ground Center | Tracking station | 40 | 60 | 60 | 105 |
| Communications | Air Force, Navy, Army Communications Centers | 100 | 100 | 100 | 150 |
| Commander Middle East Force | Contingency recovery (2 ships) | 0 | 0 | 0 | 345 |
| Pacific Command | Contingency recovery | 160 | 160 | 100 | 100 |
| Military Air Transport Service | Recovery aircraft (12 C–130's) Wx Recon | 0 | 0 | 0 | 400 |
| Caribbean Air Command | Contingency recovery | 0 | 0 | 0 | 150 |
| Miscellaneous | Radar aircraft, Air Photographic and Charting Service, Adm Aircraft, RF silence. | 90 | 100 | 120 | 45 |
| Total | | 18, 000 | 13, 000 | 17, 000 | 18, 000 |

*Table 9–II.—DOD Aircraft and Ship Support for Project Mercury*

| Aircraft | MA–6 | MA–7 | MA–8 | MA–9 |
|---|---|---|---|---|
| Atlantic Area | 82 | 74 | 65 | 65 |
| Pacific Area [a] | 12 | 12 | 41 | 58 |
| EUCOM | 16 | 16 | 16 | 27 |
| Inland U.S | 4 | 2 | 4 | 4 |
| CAIRC | 0 | 0 | 2 | 5 |
| Mauritius | 4 | 2 | 0 | 0 |
| Photo Recon | 3 | 3 | 2 | 4 |
| Weather Recon | 1 | 1 | 1 | 4 |
| Admin A/C | 4 | 4 | 3 | 4 |
| Total | 126 | 114 | 134 | 171 |
| Recovery ships | 24 | 20 | 26 | 28 |

[a] Includes 4 aircraft from RAAF.

minute after lift-off. After a 2½ hour search by the launch-site recovery group, without success, activity reverted to regular salvage operations by AMR forces augmented by two Navy minesweepers. Approximately 98 percent of the spacecraft and some parts of the launch vehicle were ultimately recovered.

On November 21, 1960, the first Mercury-Redstone mission with an unmanned spacecraft using the Redstone launch vehicle was unsuccessful because premature engine cut-off activated the emergency escape system when the launch vehicle was a few inches off the pad. The launch vehicle settled back on the pad and was damaged slightly. The spacecraft was recovered for reuse.

The unmanned Mercury-Redstone 1–A mission (MR–1A) on December 19, 1960, was a reattempt of MR–1, and was successful. The recovery phase started with visual sighting by ship and aircraft lookouts and search and rescue and homing (SARAH) detection by search aircraft prior to spacecraft landing. A helicopter hoisted the spacecraft clear of the water 15 minutes after landing and deposited it onboard ship 17 minutes later.

The spacecraft for the Mercury-Redstone mission 2 (MR–2) was launched on January 31, 1961, and carried a 37-pound chimpanzee 420 statute miles downrange. The spacecraft was tracked by the AMR almost to landing, although it had overshot by about 100 miles. Ultra-high frequency (UHF) transmissions were detected by several recovery aircraft during the flight. Recovery aircraft located the spacecraft, and a helicopter returned it to a dock landing ship. Medical support people and materiel were provided on ships, at Cape Canaveral and at Grand Bahama Island to assist in medical operations.

The second Mercury-Atlas mission (MA–2) on February 21, 1961, was successful and the landing was northeast of Antigua Island. A recovery helicopter retrieved the spacecraft 42 minutes after launch and delivered it to a dock landing ship from which it was delivered to Roosevelt Roads, Puerto Rico.

The unmanned Mercury-Atlas 3 (MA–3) mission on April 25, 1961, was planned as a one-pass orbital flight with landing east of Bermuda. All network stations except the Coastal Sentry ship were called up to support the mission. The Recovery task force was deployed to cover the designated landing area. A recovery team from U.S. Commander in Chief, Europe (USCINCEUR) provided a contingency capability to 0° longitude. A failure in the launch vehicle resulted in the Range Safety Officer's aborting the mission 40 seconds after launching. The spacecraft was retrieved 200 yards off shore by a recovery helicopter which was deployed for this purpose.

The first manned Mercury flight, Mercury-Redstone 3 (MR–3) took place on May 5, 1961. After a successful reentry, the spacecraft, with Astronaut Commander Alan B. Shepard, Jr., USN, aboard, was sighted prior to its landing in

the planned landing area by deployed helicopters. One of the helicopters delivered the Astronaut and spacecraft safely to the recovery aircraft carrier 26 minutes after landing. All phases of DOD support, including range, recovery, and medical, were excellent. For this mission the AMR Coastal Sentry ship was located in the landing area for telemetry and spacecraft-to-ground communications. Medical support consisted of aeromedical monitors aboard the Coastal Sentry Ship, emergency medical teams aboard recovery vessels and at the launch site, and a medical debriefing team at Grand Bahama Island. Aircraft of the ARS were on station to assist in search operations.

The second manned flight, Mercury-Redstone 4 (MR–4), was conducted on July 21, 1961. DOD support was comparable in scope to that of MR–3. For this mission the AMR Rose Knot ship was used in the landing area. The flight and landing phases were successful. After landing, premature actuation of the spacecraft side hatch resulted in an emergency situation in which the spacecraft filled rapidly with water and began to sink. Astronaut Major Virgil I. Grissom, USAF, egressed from the spacecraft, and, after a short but difficult period in the water lasting approximately 3 minutes, was hoisted aboard the recovery helicopter and delivered on board the recovery ship for medical examination 19 minutes after spacecraft landing. A second helicopter attempted to recover the sinking spacecraft. The weight of the flooded spacecraft exceeded the lift capability of the helicopter at full power and the pilot elected to release the spacecraft rather than to jeopardize further the safety of the helicopter and crew. The spacecraft sank in 2,800 fathoms of water.

A second attempt, to orbit an unmanned spacecraft, was scheduled for August 25, 1961. This mission was designated Mercury-Atlas 4 (MA–4). All network stations were scheduled to participate. Recovery forces were deployed similarly as had been for MA–3. Contingency support was increased in scope to include full deployment by forces from CINCLANT, and partial deployment by forces from USCINCEUR, CINCPACFLT, and ARS. Bioastronautic support included additional forces deployed for training in the launch-site area. Shortly prior to beginning the countdown, launch-vehicle problems were identified which resulted in a 3-week delay of the launch. All deployed forces were recalled, then redeployed for a September 12 launch. On September 13, the mission was successfully conducted with the spacecraft completing a one orbital pass and landing in the planned landing area. A C–54 search aircraft located the spacecraft and retrieval was accomplished by the USS *Decatur* and delivered to Bermuda Island. Network performance, with the exception of generally poor radar tracking, was good. The tracking problem was traced to the lack of operator training and poor spacecraft antenna patterns.

Mercury-Atlas 5 (MA–5) was scheduled for November 14, 1961, to carry a chimpanzee on a three-pass orbital flight. Recovery planning included the primary landing area at the end of the third pass, as well as the probable areas for landing at the end of the first and second orbital passes. Recovery forces were deployed accordingly and contingency recovery commanders planned for a full deployment. Additional medical forces included veterinary specialists for postflight care and examination of the chimpanzee, as well as a complete launch-site support team. On November 12, spacecraft problems resulted in a 2-week delay in the launch. During this period, recovery forces reverted to normal operational control, were reorganized, and redeployed for a November 29 launch date. The launch was successful and flight was normal until spacecraft problems prompted a decision to land the spacecraft at the end of the second orbital pass. Radar tracking was greatly improved through intensified training prior to the flight and better spacecraft antenna patterns as a result of a beacon modification. Reentry and landing proceeded normally and the spacecraft was sighted in the planned landing area by recovery aircraft about 260 miles south of Bermuda. It was retrieved within 80 minutes after sighting. The spacecraft and occupant were delivered to Bermuda.

Mercury-Atlas mission 6 (MA–6) on February 20, 1962, was the first manned orbital flight and involved three orbital passes. The spacecraft, with Astronaut Lieutenant Colonel John H. Glenn, USMC, aboard, landed about 166 miles due east of Grand Turk Island, approxi-

mately 4 miles from the recovery destroyer which retrieved the spacecraft 21 minutes after landing.

All network instrumentation remained operative and provided full coverage throughout the three orbital passes. Telemetry and communications were excellent in spite of some telemetry-recording and radio-propagation problems. Radar coverage was better than expected, exceeding the performance for MA–5. Although a 4-minute ionization blackout occurred during reentry, the C-band radars were able to maintain track of the spacecraft which resulted in an accurate prediction of the landing point.

The landing areas after passes 1, 2, and 3, were treated as primary recovery areas for this mission. The recovery task force comprising a total of 24 ships and 41 aircraft was stationed in the nine planned landing areas in the Atlantic Ocean. An additional 37 aircraft were standing by at Jacksonville, Florida; Bermuda, Lajes Air Force Base, Azores; BenGuerir, and Roosevelt Roads, Puerto Rico. Forces from USCINCEUR, CINCPAC, and USAF were deployed along the remaining orbital tracks for contingency recovery.

A full Bioastronautic Task Force, consisting of 159 medical people was provided by the DOD and deployed to support this mission. These people staffed or augmented 4 medical treatment facilities, 21 recovery ships, and 14 medical monitoring stations. The medical evaluation and debriefing of the astronaut was completed at the advanced medical treatment facility at Grand Turk Island on February 23, 1962.

The seventh Mercury-Atlas mission (MA–7) was launched on May 24, 1962. This mission was the second three-pass orbital flight. Astronaut Lieutenant Commander M. Scott Carpenter, USN, was the pilot for this mission. All network stations were scheduled to participate except the AMR Rose Knot ship which was undergoing modification for a command-control system. Only the landing area at the end of the third orbital pass was designated as primary for this mission, requiring support of only one aircraft carrier. The spacecraft was launched and inserted into a nominal orbit with exceptionally good precision. Just prior to retrofire, at the end of three passes, a failure in the automatic control system was noted. A manual retrofire maneuver was planned and the countdown was sent from the California site. Attitude errors at retrofire caused the spacecraft to overshoot the planned landing point by approximately 250 miles. A directional finding (D/F) bearing on the spacecraft was quickly obtained by search aircraft and a SC–54 arrived within 1 hour after spacecraft landing with an auxiliary flotation collar and other survival equipment. Helicopters were launched from the carrier U.S.S. *Intrepid* when the carrier was within flight range. Although an ARS SA–16 arrived on scene before the helicopters, the Task Force Commander decided to effect recovery by helicopter. The astronaut was retrieved 3 hours after landing and returned to the carrier. The spacecraft was retrieved by a recovery destroyer for delivery to Puerto Rico.

A postmission review held at Patrick Air Force Base, Florida, revealed the need for a more rapid flow of information between the Mercury Recovery Control Center (MRCC) at Cape Canaveral and the on-scene forces. Recovery communications equipment and procedures were changed for future missions so as to provide for a more tightly controlled recovery organization capable of quick response to changing situations.

On October 3, 1962, the eighth Mercury–Atlas mission (MA–8) was launched. This mission, planned for six passes, was successfully completed and the spacecraft, with Astronaut Commander Walter M. Schirra, USN, aboard, landed in the primary landing area approximately 4½ miles from the recovery aircraft carrier. For the first time in the Mercury Project, recovery forces were deployed in the Pacific Ocean for a primary landing northeast of Midway Island. The landing area in the Atlantic Ocean at the end of the third pass was also treated as a primary area in the event that a full six-orbital mission could not be completed. Contingency recovery forces were expanded to cover the additional ground tracks in the South Atlantic, Caribbean, and western Pacific Ocean. The AMR Coastal Sentry ship was positioned in the Pacific Ocean to monitor the planned retrofire maneuver. Two S-band radar ships from the Pacific Missile Range and an Army C-band radar ship were positioned uprange from the primary landing area for reentry tracking. The Bioastronautic Task Force con-

sisted of 84 medical specialists assigned to the launch area, network stations, and recovery units. An additional 22 specialists were available on a standby basis.

Centralized operational control together with the cooperation of the DOD forces participating in MA–8 were instrumental in achieving an integrated and responsive organization.

The ninth Mercury–Atlas mission (MA–9) was launched on May 15, 1963. This manned 1-day mission was planned for 22 orbital passes with the primary landing area in the Pacific Ocean southeast of Midway Island. The MA–9 spacecraft, with Astronaut Major Gordon Cooper, USAF, aboard, was placed into a near-perfect orbit by the Atlas launch vehicle. After 33 hours of normal flight during which the major objectives were met, a malfunction in the spacecraft control system required manual control of the spacecraft during retrofire and reentry. This was accomplished successfully and precisely by the astronaut and the spacecraft landed in the primary landing area within 4½ miles of the recovery aircraft carrier.

There were a total of 26 planned landing areas in the Atlantic and Pacific Oceans for the MA–9 mission. These areas were selected so that the ships of the Atlantic and Pacific task forces could cover more than one area. A worldwide deployment of contingency recovery forces was required to cover the entire ground track of the spacecraft. All theater forces were augmented by long-range C–130 MATS airplanes. There were 98 aircraft deployed for contingency recovery by the Air Rescue Service (ARS), Caribbean Air Command (CAIRC), Pacific Air Forces (PACAF), and CINCUSAREUR. Two AMR network ships were positioned in the Pacific Ocean to give command-control coverage. Reentry tracking in the Atlantic and the Pacific was available from two C-band radar ships. The Bioastronautic Task Force included 78 medical people deployed, 32 specialty team members on standby, two specialty team hospitals, and 7 recovery support hospitals.

Support efforts of DOD also included the successful accomplishment of voice relays both in the Atlantic and Pacific. Relay to Mercury Control Center (MCC) of the astronaut's voice while in orbit was obtained by the AMR C–130's stationed near Bermuda. During reentry and after landing, voice communications were relayed through PMR aircraft to the Hawaii network site where it was patched through network voice circuits to MCC. Radar airplanes of the Air Defense Command stationed in the Atlantic and Pacific obtained skin track of the spacecraft. The network provided excellent tracking coverage throughout the flight, considering the lengthy operating period for the equipment and long working hours for site people. Thoroughness in planning and excellent performance of assigned missions by DOD forces were reflected in the success of the MA–9 mission.

### Concluding Remarks

Many changes in procedures and techniques used in providing Department of Defense support were developed during the course of the Mercury Project. Many lessons were learned and put into effect during successive missions; however, only those significant items which may have possible application in supporting future manned space programs are described.

The organization for the coordination and control of the overall DOD participation in Project Mercury was highly satisfactory. The designation of a DOD Representative for coordination of DOD support for Project Mercury operations was effective in that NASA was provided with a single point-of-contact for the submission of their overall DOD support requirements.

The operation of the global Mercury network comprising DOD ranges, NASA stations, and two stations in Australia was a significant achievement in coordinated team effort and was only accomplished by the complete cooperation of all concerned. Network management and operational procedures were clearly defined and compiled in a comprehensive joint DOD–NASA Mercury Network Operations Directive which proved to be a very useful and effective document.

The demonstrated ability of several ranges to combine their collective resources effectively to support global missions proves the possibility of combining all such national missile tracking resources under a single management control for the support of all missile and space programs of all agencies.

The integration of radar-tracking equipment into a tracking system at the DOD missile ranges increased the capability of each range to support future missions. Technological experience and achievements of each range were pooled to permit all ranges to take advantage of such advancements or modifications.

The application of relay techniques for transmitting remote telemetry data from the downrange stations, derived from AMR experience in data transmission, was reported to NASA for possible adaptation to the wire and radio circuits of the Mercury network. Subsequently NASA secured a telephone line for data transmission between Pt. Arguello and the Mercury Control Center. During the ninth Mercury-Atlas mission the Mercury Control Center was supplied with a real-time display of electrocardiograph functions from the DOD sites at California, Antigua, and at Ascension. In addition to increasing the potential at each site by such improvements, a considerable saving in research and development costs was also realized by virtue of this exchange of technical information.

The use of radar-tracking aircraft during Mercury missions and especially the results obtained during the reentry phase of the MA–9 mission added significantly to the flexibility of network operations.

The use of the vast communications resources within the DOD and their integration into existing NASA and commercial systems to support network and recovery operations contributed significantly to the operational success of the project.

One of the more important considerations for support of Mercury operational planning was to provide for the safe and rapid recovery of the astronaut. Plans made by the DOD elements provided for the deployment of forces in a large number of strategic locations to cover possible aborts during all phases of the mission. Much of the effort in training was expended by forces that were deployed to act in contingency situations which essentially never developed. Their efforts, nevertheless, contributed to the success of the recovery mission.

Providing support to Mercury flights has contributed greatly to DOD's knowledge and experience in areas of launch, network, recovery, communications, and medical space operations. Future space-flight operations can be effectively supported by applying the experience and procedures derived during Project Mercury.

# 10. ASTRONAUT TRAINING

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## Summary

Any training program must be based on three factors: the requirements of the job, the characteristics of the trainees, and the training facilities available. Each factor is briefly discussed and its effect upon the nature of the training program is indicated. Selection of the Mercury astronauts began in January 1959. They reported at the Manned Spacecraft Center in April of that year and took part in a group training program for the next 2 years. In April 1961, when the Mercury manned flight program began, a special preflight preparation program was conducted with each of the pilots and his backup designated for a flight. The remainder of the group took part in development and operational activities and did limited training to maintain the proficiency developed during the group training program.

The group training program consisted of five major areas: (1) basic astronautical science instruction, (2) systems training, (3) spacecraft control training, (4) environmental familiarization, and (5) egress and survival training. The specific preflight preparation programs involved: (1) integrating the pilot with the spacecraft, (2) specific systems training, (3) development and practice of the specific mission flight plan, (4) training with flight controllers, and (5) medical and physical preparation. All of the Mercury trainers and training facilities are briefly listed and discussed, and this section concludes with an evaluation of the training devices and of the various phases of the training program.

Overall, the Mercury training program appears to have been successful in providing experienced pilots with the detailed spacecraft operation and systems information and skills which were required for them to make the transition from airplanes to spacecraft. The program seems to have been well suited to the requirements of the Mercury Project and future programs will make use of the same basic techniques. In retrospect, some of the emphasis on environmental familiarization might have been reduced, and more complete simulation of the external view from the spacecraft should have been provided. However, the great majority of the trainers and training activities have been both beneficial and necessary to produce the level of readiness that was demonstrated in the flight program.

## Introduction

The Mercury training program was the first opportunity to prepare individuals for space flight. In general, however, the techniques used were not basically new or unique to this project. Rather, standard training techniques and training equipment approaches which had been used for many years in aviation were adapted for preparing the astronauts for their flights. From the beginning, the role of the astronaut has been conceived as being active and highly similar to that of the test pilot who carries out the initial flights of new aircraft. While the Project Mercury drew heavily upon flight training methodology, there were certain specific requirements of this program which were significant in determining its basic form. It is perhaps worth keeping these requirements in mind in a review of the Mercury training procedures:

(1) The Mercury program was not a mass training program, only seven individuals were involved, and, therefore, it was possible to reduce the formality of the program and to use a number of shortcuts which would not have been

feasible in the larger aviation training programs.

(2) The participants in the training program were experienced individuals who were already well along in preparation for space flight. This not only greatly reduced the overall amount of training necessary, it was also possible to emphasize individual initiative and responsibility for their training status.

(3) The training program had to be flexible because the spacecraft which the astronaut was being trained to operate was under development and therefore was being modified according to mission requirements.

(4) The training program had to be designed to help feed back into the developmental process. The astronauts were expected to aid the development engineers by participating in the design and review of many of the spacecraft systems, and the training activities were frequently combined with systems tests to evaluate both onboard and crew equipment.

(5) Unlike flight training, actual training in space was not feasible. There was a complete dependence upon ground simulator training until the astronaut flew the mission for which he had been preparing.

(6) The training had to be designed to tie in with the training and preparation of other operational groups such as the flight controllers.

(7) The significance of the program to our national prestige, the very great interest of the public, and the large cost resulted in an unusually strong emphasis upon a very high level of reliability, perfection, and precision in the man's performance.

## Training-Program Characteristics

Any training program must be based on three major factors: the job requirements, the characteristics of the trainees, and the training facilities which are available. These factors are discussed in the following paragraphs.

### Characteristics of Mercury Astronaut's Job

While the Mercury spacecraft was designed to complete a limited preprogramed mission on a completely automatic basis, from the very beginning manual controls were also provided. It was recognized that the man could provide increased systems reliability and give flexibility to the mission by allowing for a greater variety of maneuvers and scientific observations. The decision to provide for complete manual operation was highly significant for the crew training program because it meant that there would be a requirement for an individual who could skillfully manage the vehicle, as well as merely tolerate the physical stresses of the flight.

The major tasks (refs. 1 and 2) which can be identified from an analysis of the Mercury vehicle and its mission, involve:

(1) Sequence monitoring—monitoring all of the critical phases of the space mission, such as lift-off, staging of the launch vehicle, the separation of the escape tower, the separation of the spacecraft from the launch vehicle, firing of the retrorockets, and deployment of the parachute.

(2) Systems management—operation of all of the onboard systems and the management of the critical consumable supplies to insure that any out-of-tolerance condition is recognized and corrected before an emergency situation develops.

(3) Attitude control—maneuvering the vehicle to the proper relationship to the earth or orbital path whenever it is required during the mission.

(4) Navigation—being able to determine the spacecraft's position in orbit at any time and determining the critical retrofire time.

(5) Communications—operating the radio links to keep the ground control center informed of his status.

(6) Research observations—carrying out the special activities related to research and the evaluation of spacecraft function under flight conditions. The difficulty of performing these tasks was increased by the presence of environmental conditions, such as high acceleration, reduced pressure, heat, noise, vibration, and weightlessness.

In addition to these tasks involved in the actual operation of spacecraft, the Mercury astronauts were expected to contribute to a number of areas in the Mercury program. These included four main areas:

(1) Design of the Mercury spacecraft.

(2) Development of operational procedures.

(3) Development of inflight test equipment.

It was desired to carry out tests of the spacecraft function, of special advanced systems and components, and to do scientific research during

the space flight that required the astronauts' participation in the development of a number of specialized kinds of equipment.

(4) Contribution to public relations activities. The astronauts served as excellent spokesmen for the program and were an important aid in meeting the requirement set by Congress to keep the public informed on the space program.

### Characteristics of Trainees

The job requirements discussed in the previous section required individuals with high skill levels, appropriate personality traits, and a high level of physical fitness. The requirements under each of these areas are summarized as follows:

(1) In the area of aptitude and ability factors, the individual needed:

(a) A good engineering knowledge

(b) A good knowledge of operational procedures typical of aircraft or missile systems

(c) General scientific knowledge and research skills.

(d) High intelligence.

(e) Psychomotor skills similar to those required to operate aircraft

(2) In the area of personality factors, the candidate had to demonstrate:

(a) Good stress tolerance

(b) A good ability to make decisions

(c) Ability to work with others

(d) Emotional maturity

(e) A strong motivation for the program

(3) The physical requirements included:

(a) Freedom from disease or disabilities

(b) A resistance to the physical stresses of space flight accelerations, reduced pressure, weightlessness, high temperatures, and so forth

(c) Medium size so that they could be adequately accommodated by the relatively small Mercury spacecraft.

Initial planning during the fall of 1958 resulted in the definition of five basic requirements for Mercury crew members: age, 39 or below; height, 5 feet 11 inches or below; graduate of a test pilot school; qualified to fly jet airplanes; with 1,500 hours of jet flying time; and a bachelor degree in science, engineering, or the equivalent. During the first weeks of January 1959, a selection board reviewed the records of 508 military test pilots and selected the 110 who met the above requirements. The 69 most highly qualified of these candidates were invited by the services to come to the Pentagon to receive a briefing on Project Mercury and to be interviewed by the NASA Space Task Group.

On the basis of these interviews, 32 were selected to proceed to the Lovelace Clinic for a week of detailed physiological examinations and then to the Wright Field Aeromedical Laboratory for a week of stress tests (refs. 3 to 6). Data from these two testing programs were summarized and reviewed at the Space Task Group during the first week of April 1959. In all, 18 men were found to be medically qualified without reservation and, of these, the seven most technically qualified were selected to enter training.

### Training Facilities

Table 10–I summarizes all of the major training facilities used in the Mercury Astronaut Training Program. Included are training devices and other facilities used for significant areas of the training program. From the table, it can be seen that there were a large number of facilities used. This resulted from at least three factors.

(1) Since the program was a first effort of its kind, it seemed appropriate to try all facilities to get a better feel for the relative importance of various types of experiences to the training.

(2) It was generally impossible to simulate more than one or two of the environmental conditions at any given facility. Therefore, it was necessary to use many different devices to obtain experience with all aspects of the environment.

(3) Most of the training devices had to be simple and rudimentary because the simulation techniques for space flight were in their infancy, and the training program was based on an accelerated schedule.

Table 10–I also lists the availability, date, approximate training time per astronaut, estimates of cost, lead time, and support time for each of the major training devices. The scheduling of some types of training activities had to be held up pending delivery or completion of this equipment. Also as can be seen from the source or location of each device in table 10–I, these training facilities were spread out over

*Table 10–I.—Trainer Summary*

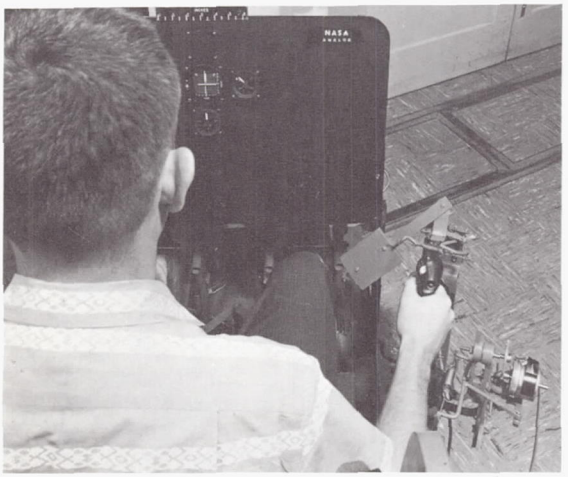
| Identifying letter from fig. 10–1 | Trainer | Primary purpose of trainer | Approximate date available | Approximate training time per astronaut, hr. | Approximate cost, dollars | Approximate lead time, months | Approximate support time, man-hours | Source | Assessment | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Essential | Desirable | Early availability | Questionable value |
| a | Analog trainer no. 1. | Attitude control. | Apr. 1959 | 8 | ---------- | 0 | 200 | NASA Langley Research Center. | | x | x | |
| b | Proficiency airplane flights. | General performance proficiency. | May 1959 | 460 | ---------- | 0 | 60, 000 | U.S. Air Force and inhouse. | | x | | |
| c | Centrifuge simulations. | Acceleration training; reentry control. | Aug. 1959 | 48 | 500, 000 | 4 | 15, 000 | U.S. Navy, Johnsville, Pa. | x | | | |
| d | ALFA trainer | Attitude control. | Oct. 1959 | 12 | 50, 000 | 6 | 150 | Inhouse | x | | | |
| e | Analog trainer no. 2. | Attitude control, pressure-suit training. | Oct. 1959 | 10 | 20, 000 | 3 | 200 | Inhouse | | x | x | |
| f | Navy slowly revolving room. | Disorientation familiarization. | Oct. 1959 | 1 | ---------- | 0 | 15 | U.S. Navy, Pensacola, Fla. | | | | x |
| g | Zero-g airplane flights. | Zero-g familiarization. | Dec. 1959 | 0. 7 | ---------- | 0 | 1, 000 | U.S. Air Force | | x | | |
| h | Chapel Hill Planetarium | Star recognition training | Feb. 1960 | 28 | ---------- | 0 | 600 | University of North Carolina | x | | | |
| i | MASTIF trainer | Disorientation familiarization | Feb. 1960 | 4 | ---------- | 0 | 300 | NASA Lewis Research Center | | x | | |
| j | Egress trainer | Egress training | Feb. 1960 | 25 | 119, 000 | 10 | 1, 000 | McDonnell Aircraft Corp. | x | | | |
| k | Procedures trainers (2) | Systems management, attitude control, mission training | June 1960 | 101 | 4, 000, 000 | 12 | 100, 000 | McDonnell Aircraft Corp. | x | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| l | ECS trainer | Environmental control system management | Nov. 1960 | 3 | 228, 000 | 12 | 1, 000 | McDonnell Aircraft Corp. | | | | x |
| m | Attitude instrument display mockup | Characteristics of attitude instruments | Jan. 1961 | 10 | 5, 000 | 4 | 50 | Inhouse | x | | | |
| n | Ground recognition trainer | Periscope training and terrain familiarization | Apr. 1961 | 1 | 2, 000 | 3 | 5 | Inhouse | | | | x |
| o | Yaw recognition trainer | Out-the-window yaw angle recognition | Sept. 1962 | 2 | 1, 000 | 1 | 30 | Inhouse | x | | | |
| p | Virtual image celestial display | Attitude control at night; star recognition training | May 1963 | 2 | | 12 | 75 | Farrand Optical Co. | x | | | |

the country. This resulted in a large amount of travel for the astronauts. As a result, their time was used somewhat less efficiently than if all the training facilities had been available from the beginning of the program at MSC. Most of these facilities are pictured in figures 10–1(a) to 10–1(p).

### Training Chronology

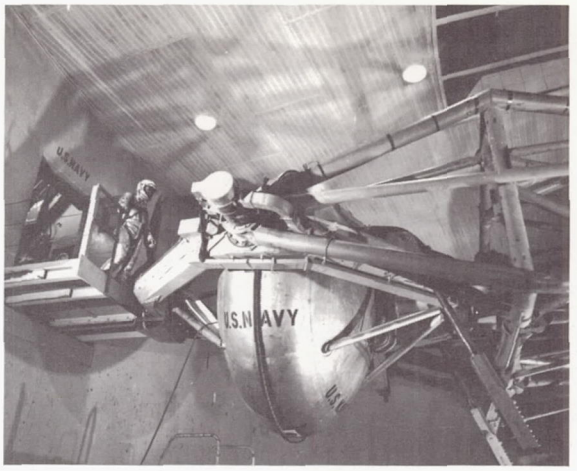
Figure 10–2 presents a chronology of the Mercury training program. The astronaut selection program occupied the period from January to April 1959. The group training program ran for approximately 2 years, to April 1961. After April 1961, the manned flight program began. Prior to each flight, a preflight preparation program was conducted for the pilot and his backup. The length of this



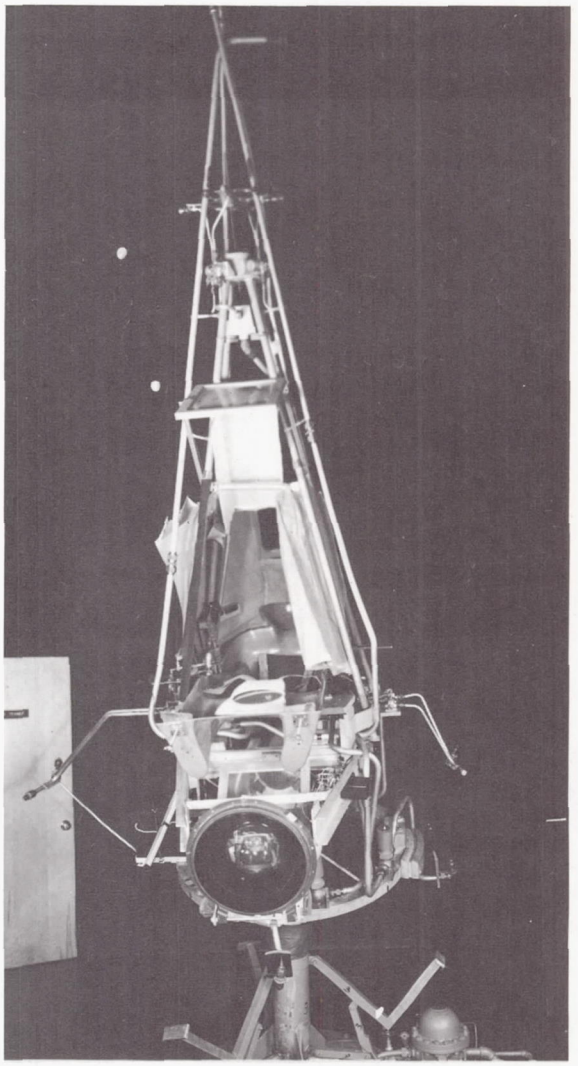
(a) Langley analog computer simulator.



(b) Aircraft used for proficiency flights.



(c) Centrifuge acceleration facility.



(d) ALFA trainer.

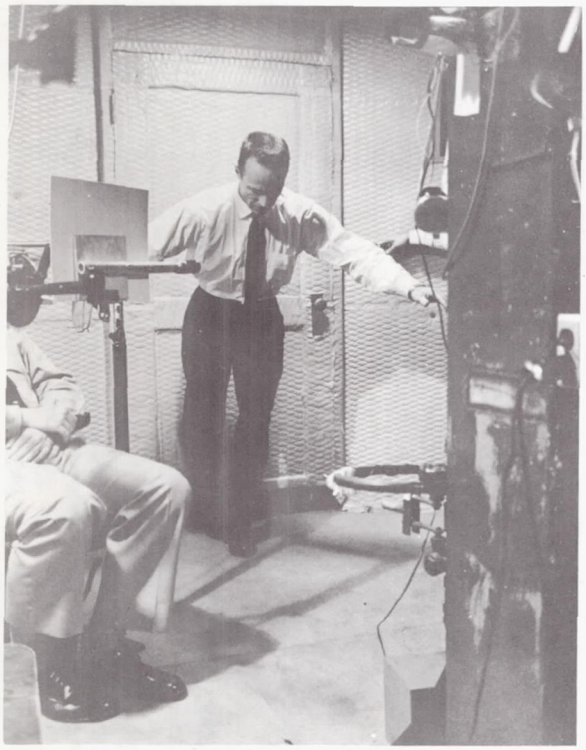
FIGURE 10–1.—Photographs of various training facilities.



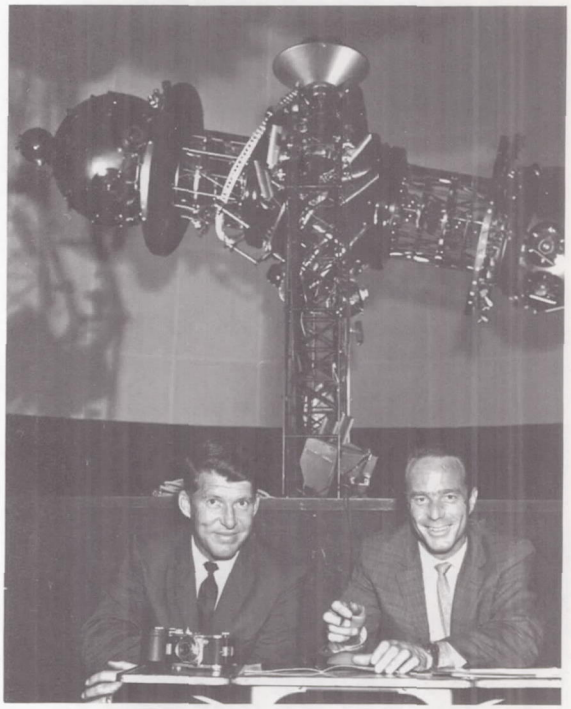
(e) Analog computer trainer no. 2.



(g) Zero-g airplane flights.

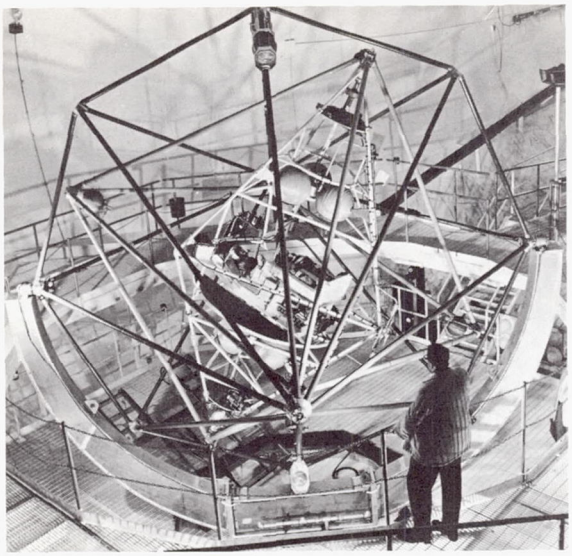


(f) Slowly revolving room.

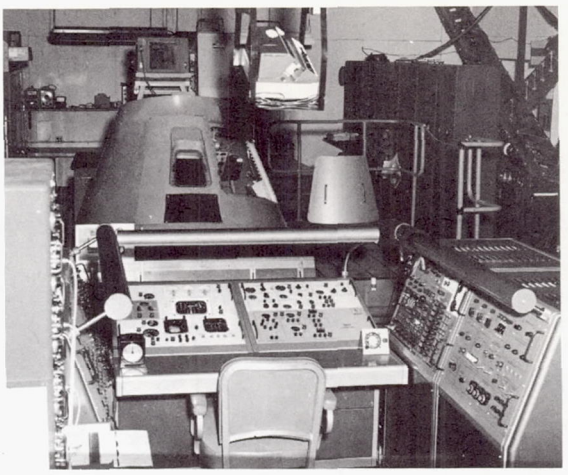


(h) Chapel Hill Planetarium.

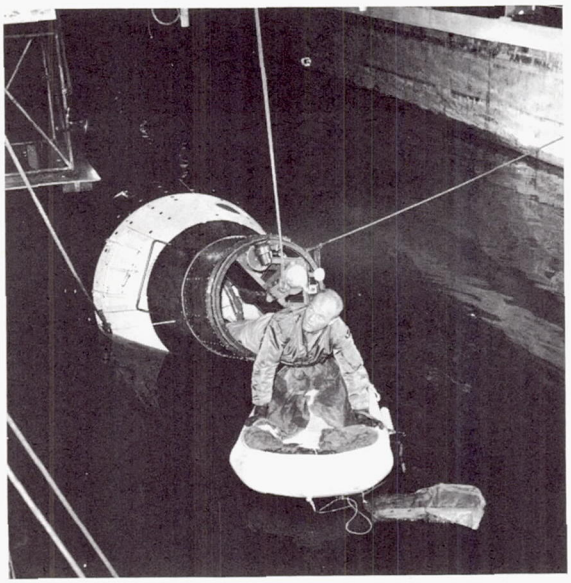
FIGURE 10–1.—Continued.



(i) MASTIF trainer.



(k) Procedures trainer.

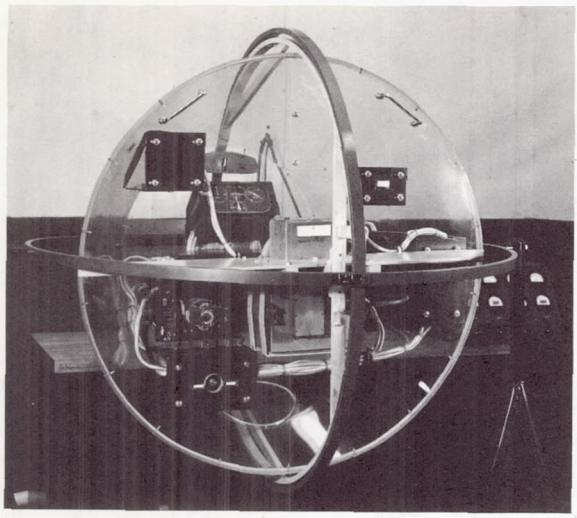


(j) Egress trainer.

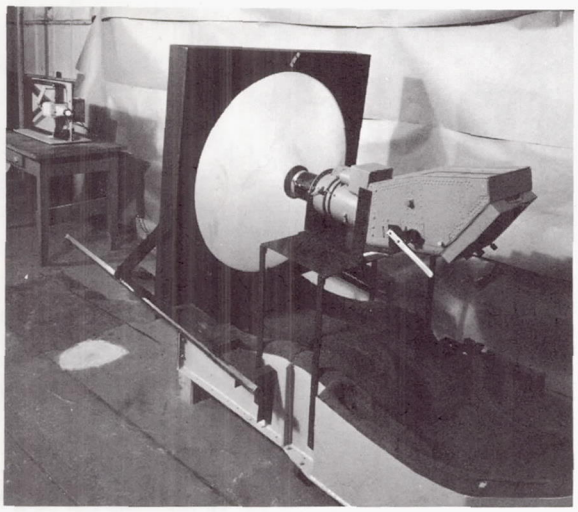


(l) ECS trainer.

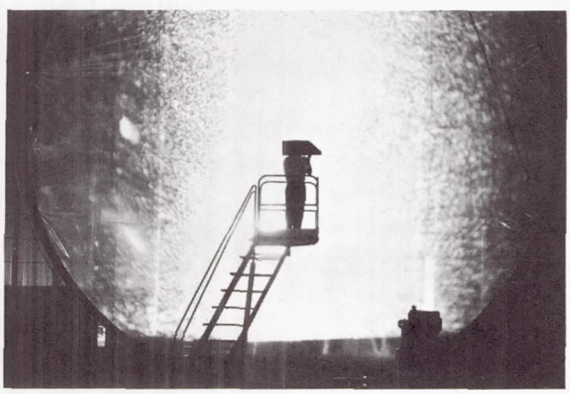
FIGURE 10–1.—Continued.



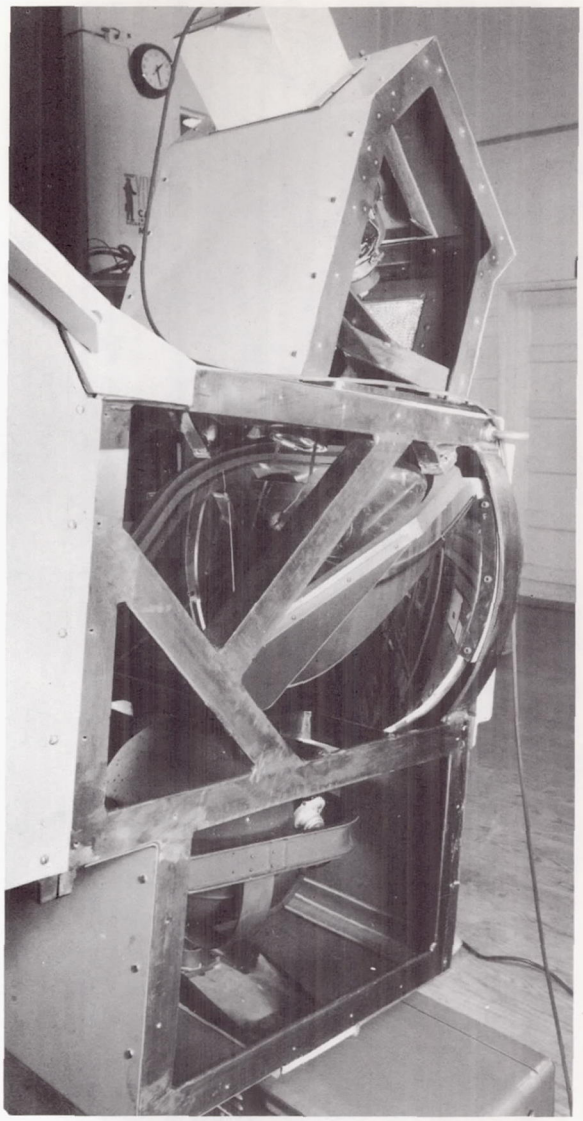
(m) Attitude instrument display mockup.



(n) Ground-features recognition trainer.



(o) Yaw recognition trainer.



(p) Virtual image celestial display.

FIGURE 10–1.—Concluded.

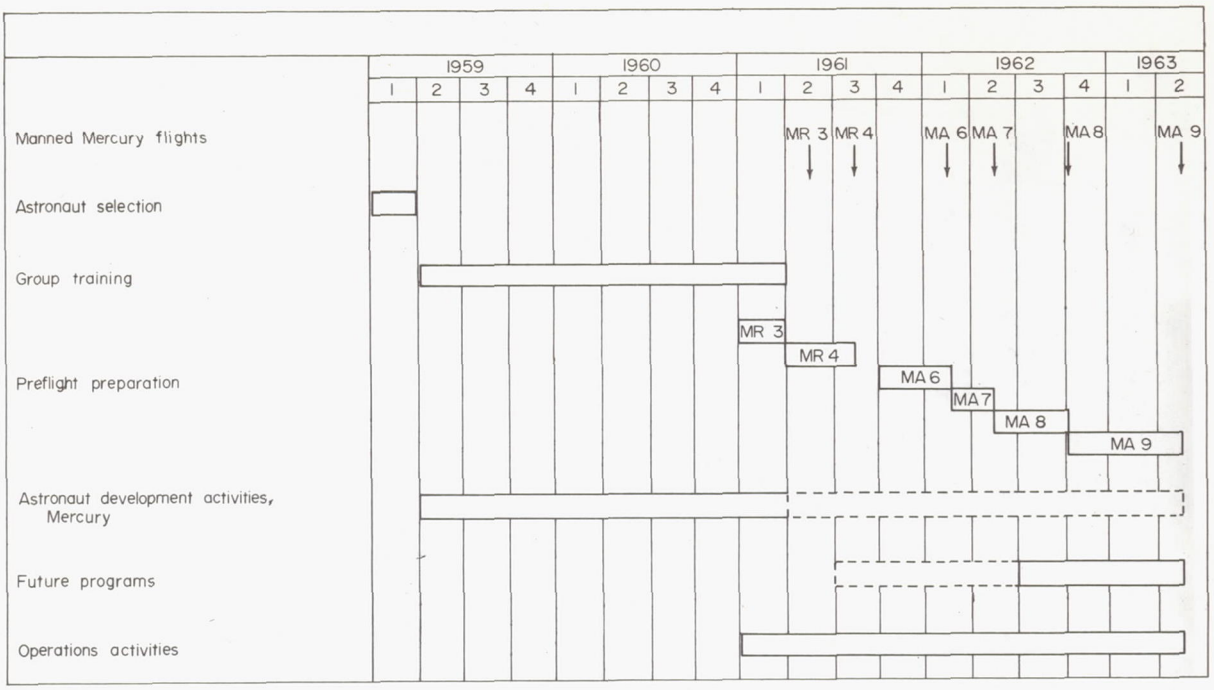



FIGURE 10–2.—Chronology of Mercury training program.

program depended upon the time available between flights and on the nature of the flight. In general, the backup pilot on one flight was selected as primary pilot for the next mission. In this way, the actual preflight preparation of each pilot encompassed close to 6 months—the first half as a backup and the second half as the primary pilot.

The pilots' contribution to the development activities in the Mercury program began soon after they reported to the NASA and had had sufficient indoctrination on the Mercury spacecraft systems. The astronauts participated in planning for the programs to follow Mercury which began in 1961 and became greatly accelerated in 1962.

Each man was assigned to a Mercury network station as voice communicator. Service in this capacity normally involved a minimum of 3, or more, weeks. This activity in connection with Mercury operations began with the manned Redstone flights in 1961 and became greatly amplified with the manned orbital flights in 1962 and 1963. After the termination of the group training program, they had to devote time to maintaining their proficiency, in addition to these operational requirements.

## Group Training Program

The group training program consisted of five major areas which are described in the following paragraphs. Portions of this program have previously been described by Astronaut Slayton in ref. 7 and others (ref. 6 and 8).

### Basic Science Program

An initial phase of the Mercury astronaut training program consisted of brief but comprehensive courses in the astronautical sciences. The astronauts had had considerable training in the aeronautical sciences, but most had not had an opportunity to acquire the basic knowledge in such subjects as rocket propulsion and space mechanics which were required in the Mercury flight program. Training in the space sciences enabled the astronauts to function better as observers of inflight phenomena and provided a basis for better understanding of the technical aspects of the Mercury spacecraft and vehicle systems. The series of courses listed in table 10–II was conducted with the cooperation of the NASA Langley Research Center. Time did not permit a more extensive program although it would have been desirable.

*Table 10–II.—Lectures on Space Sciences*

| Subject | Hours |
|---|---|
| 1. Elementary Mechanics and Aerodynamics | 10 |
| 2. Principles of Guidance and Control | 4 |
| 3. Navigation in Space | 6 |
| 4. Elements of Communication | 2 |
| 5. Space Physics | 12 |
| 6. Basic Physiology | 8 |

**Systems Training**

A large portion of the training program was devoted to familiarizing the astronauts with the Mercury systems. This knowledge was not only basic to all of their training activities but was the essential basis of their contribution to the development program. The primary requirements of this training were: to develop a basic understanding of the nature and characteristics of each system; to build on this understanding a knowledge of the system operation and function; and, finally, to develop, in the Mercury procedures trainers and the spacecraft, skill in managing the onboard systems.

*Systems briefings.*—The systems training began with a series of briefings given by specialists within the Space Task Group. The first set of lectures covered the Mercury systems and was followed by another group of lectures covering operational areas. These lectures were followed by a series of somewhat more detailed systems briefings by contractor personnel at the various contractor facilities. Periodically, throughout the 2 years of the group training program, systems lectures were repeated.

*Contractor visits.*—The astronauts visited contractor plants and other NASA centers in order to get a firsthand view of the developing hardware and of the operational facilities.

*Manuals.*—Documentation of the Mercury systems was a particularly difficult problem because the spacecraft was under development. The first set of systems lectures were used as the basis for the Mercury Familiarization Manual (ref. 9). This manual became the basic systems document used by the astronaut.

A second manual, which was developed later in the program and which emphasized the operational aspects of the systems management problem, was the Capsule (Spacecraft) Flight Operations Manual (ref. 10). This document was printed in a size small enough to be carried in the pocket of the flight jacket with the intention that it could be carried along on flights, if desired. In actual practice, it was not carried with the flight but was used during some trainer runs. A third publication used extensively in training was the Flight Controller's Handbook, which was developed within the Manned Spacecraft Center (see paper 15) and which provided a number of useful diagrams for analyzing system malfunctions.

*Specialty Assignments.*—To insure that the astronauts had available to them the most up-to-date information possible, they participated in the engineering reviews and other meetings on the spacecraft systems. Since no one man could cover all of these meetings, each astronaut was assigned to a specialty area (ref. 7). Each man attended meetings in his area and reported back to the group.

*Mercury Procedures Trainers.*—The bulk of the operational training in the Mercury systems was achieved on the Mercury Procedures Trainers (MPT). The name "procedures trainers" is actually a misnomer since these devices could better be classified as flight simulators. Initially, a very simple open-loop device had been considered for training in the basic launch procedures. This was to be supplemented later by a complete flight trainer. However, the time available for development and delivery of these training devices was so short that it was decided to combine the two into a single trainer. In this trainer, it was possible to simulate the operation of all of the Mercury systems and induce approximately 275 separate system failures (ref. 11). Provisions were made to pressurize the pressure suits. However, with the exception of the indicator readings, the actual environmental conditions in the cabin were not provided. Two of these units were procured in order to have one available at the launch site to be used in prelaunch training, while the other was used at the main training base at Langley Field, Va. These two procedures trainers differed slightly in their provisions for animating attitude control system, as is described later, but they were essentially identical in their capability to simulate the operation of onboard systems.

Initial training began by reviewing each system separately in the trainer. The normal operation of each system and all of the failures which could be simulated were demonstrated during this initial period. Following this, a series of both Redstone and Atlas simulated flights were made for each student, during which simulated emergencies were kept to a minimum in order to allow the astronauts to become familiar with the timing of the normal missions. Once they were generally familiar with the timing of the missions and the normal indications, the numbers and types of malfunctions were increased. By the end of the group training period, all the astronauts had made a large number of Atlas and Redstone runs and had had an opportunity to experience most of the major emergencies.

*Environmental Control Systems Trainer.*— Additional training in the operation of the environmental control system was provided by the environmental control systems trainer which was a heavy shell mock-up with a prototype spacecraft environmental system. The device used was delivered to NASA in November 1960 and installed in a man-rated vacuum chamber at the U.S. Naval Air Crew Equipment Laboratory in Philadelphia (fig. 10–1(l)). During December of 1960 and January of 1961, the astronauts participated in a program of system familiarization that included being exposed to a simulated reentry heat pulse and approximately 2 hours of the expected postlanding temperature. During these runs, the astronauts wore the pressure suits and became familiar with function of the suits when associated with the environmental control system. However, since a provision had been made for simulating the suit function in the procedures trainer, this type of training was not considered essential. This was particularly true since the astronauts received further first-hand familiarization to the environmental control system by participating in the preflight checkout of the spacecraft environmental control system at the launch site.

#### Attitude Control Training

A number of fixed and moving based simulators had to be employed because no single trainer was capable of simulating all of the tasks on all of the control systems under all environmental conditions (ref. 12). The function of each of the principal control attitude trainers is summarized in table 10–III. This table lists the attitude control trainers and the spacecraft control systems which could be simulated, the reference systems which were available to the pilots, tasks which could be practiced, environmental conditions simulated, and finally whether or not attitude tasks could be practiced in conjunction with other flight activities. Each of these trainers is briefly described in the following paragraphs.

*Table 10–III.—Attitude Control Trainer Summary*

| Referenced to figure 10–1 | Trainer | Control systems [a] | | | | Reference systems | | | | Types of tasks | | | | Environmental conditions | | | Use while performing other tasks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MP | FBW | RC | Mixed | Instruments | Window | Periscope | Mixed | Orbit attitude control | Retrofire | Reentry rate damping | Recovery from tumbling maneuvers | Linear acceleration | Angular acceleration | Pressure suit | |
| a | Analog trainer no. 1 | x | x | | | x | | | | x | x | x | | | | | |
| e | Analog trainer no. 2 | x | | | | x | | | | x | x | x | | | | x | |
| k | Procedures trainer no. 1 | x | x | x | x | x | [b] | x | x | x | x | x | | | | x | x |
| k | Procedures trainer no. 2 | x | x | x | x | x | | | | x | x | [c] | | | | x | x |
| o | Yaw recognition trainer | | | | | | x | | | | | | | | | | |
| m | Attitude Instrument display mock-up | | | | | x | | | | x | | | x | | | | |
| h | Ground recognition trainer | | | | | | | x | | | | | | | | | |
| d | ALFA | x | x | | | x | x | x | x | x | x | | | | x | | |
| i | MASTIF | x | | | | x | | | | | | | x | | x | | |
| c | Centrifuge | x | | | | x | | | | x | x | x | | x | | x | x |

[a] MP—Manual proportional.
FBW—Fly-by-wire.
RC—Rate command.

[b] Added to MPT no. 2 late in training program.

[c] Virtual image celestial display added to MPT no. 2 just prior to last flight.

*Analog trainer.*—The analog computer trainer provided the first simulation of the astronaut's manual flight-control task in Project Mercury. The simulator (fig. 10–1(a)) was set up by Langley Research Center personnel at the inception of Project Mercury and was used heavily during the first half of 1959, both for engineering feasibility tests and for introducing the Mercury flight control tasks to the astronauts.

*Analog trainer no. 2.*—The trainer was activated in the latter half of 1959. The simulator (fig. 10–1(e)) utilized a special-purpose a-c analog computer obtained from an obsolete F–100 gunnery trainer. Realism was enhanced by the use of an early type molded styrofoam couch and a prototype Mercury three-axis controller supplied by the contractor. Aside from providing the astronaut with his first opportunity to practice attitude control in the pressurized suit, this trainer was used to perform a number of engineering feasibility studies.

*Mercury Procedures Trainers.*—The Mercury procedures trainer no. 1, housed in the NASA Full-Scale Tunnel at Langley Air Force Base, Va., and trainer no. 2, housed in the Mercury Control Center (fig. 10–1(k)) at Cape Canaveral, Fla., were the most valuable flight-crew trainers used in the Mercury Project.

The decision to provide two trainers was found to be sound since, in addition to the astronauts' requirements, there were requirements to use both Mercury Procedures Trainers in conjunction with simulations in the flight controller training program. Trainer No. 1 was used in conjunction with the remote site simulator at Langley Air Force Base, Va.; and trainer no. 2, with the Control Center Mission Training Complex at the launch site. (See paper 15.)

Both trainers were delivered without analog computers for animating the rate-and-attitude flight instruments. Therefore, procedures trainer no. 1 was connected to the same computer used in the analog trainer no. 2. This computer allowed activation of all of the 22 possible combinations of manual and/or automatic attitude controls that were provided in the Mercury spacecraft. Three months after delivery, procedures trainer no. 2 was supplied with a small-capacity general-purpose analog computer which permitted activation of only the manual-control modes for the orbital phase of flight. Approximately 6 months prior to completion of Project Mercury, additional equipment was obtained to provide manual damping practice during reentry.

Trainer no. 1 had an active periscope display consisting of a moving dot on the face of a cathode ray tube which was activated by the hand controller and the analog computer. Very late in the project a new, versatile, virtual image display was also added to trainer no. 1. This display was used briefly for training prior to the last Mercury flight.

*Virtual-image celestial display.*—Because of the state-of-the-art of space flight external-view simulation at the outset of the Mercury project and the compressed time schedule, no external view other than that through the periscope was provided on MPT no. 1 at the time of delivery of the procedures trainers. However, considerable effort was expended in trying to develop new and versatile displays. One result of these efforts was the virtual-image viewing system (fig. 10–1(p)). The first working model of the system was delivered and installed on the MPT no. 1 in time for limited training prior to the MA–9 flight. This display could simultaneously accept inputs ranging from three-dimensional models to closed-circuit television or film strips. However, the only display available at the time of the MA–9 flight was a star view. The stars were produced by setting ball-bearings of various sizes into the surface of a 12-inch diameter, hollow magnesium sphere which was gimballed and driven by a computer. The ball bearings, upon illumination by a point light source, produce exceedingly realistic point sources of light of the desired brightness to represent the star fields.

*Yaw-recognition trainer.*—Prior to the MA–8 six-orbital-pass mission, there was considerable concern regarding whether or not the pilot would be able to detect his yaw position solely by use of the slow translation of terrain or clouds viewed out the window of his spacecraft. The pilot's ability to determine accurately yaw by using out-the-window references is all-important if his gyro altitude information was lacking during retrofire as in the MA–9 flight. In this case, Astronaut Cooper had to rely on his window scene to determine heading or yaw position accurately for retrofire. (See paper 17.)

In order to give the astronauts a preview of the out-the-window motion cues they would have in orbit, a yaw-recognition trainer (fig. 10–1(o)) was conceived, built, and activated in about 2 weeks. The trainer consisted of a 33-foot diameter convex-lens-shaped screen, one surface of which represented either the earth's surface or a constant-altitude cloud deck. This surface was made of polyethylene plastic and was used to display a real, moving image of simulated clouds produced by a film strip moving at the proper speed through a slide projector. The speed of the image movement duplicated the in-flight apparent movement between the spacecraft and the ground by having the observer view the scene from a point at the middle of the lens while standing 2 feet away from the surface. To heighten realism, the flight crews wore a box over their heads which had an opening which simulated the proper size and shape of the spacecraft window.

The MA–8 and MA–9 flight crews utilized the yaw recognition trainer prior to their flights. The other astronauts used the trainer subsequent to their flights. All of the pilots who had flown orbital flights reported that it duplicated almost exactly the visual yaw motion cues observed from the spacecraft.

*Attitude instrument display mock-up.*—The attitude instrument display mock-up (fig. 10–1 (m)) consisted of a half-scale transparent model of the Mercury spacecraft mounted within a four-gimbal all-attitude support. The mock-up contained the actual Mercury rate and attitude indicators without horizon scanner or ASCS logic hardware. The exterior covers of the attitude gyroscopes were removed so that the trainee could observe the manner in which the attitude gyros tumbled during simulated motions of the spacecraft. The device illustrated how the attitude indicators can read incorrectly as a result of various spacecraft attitudes occurring at times when the floating gyroscope axes are not parallel to the spacecraft axes. The major purpose of this training device was to teach the astronauts how to regain use of the attitude gyros and attitude indicating system if correct reference were lost as a result of the tumbling of the gyros or the interference of the "repeater" stops. This conceptual trainer was very useful and each flight crew spent several hours studying the maneuvers planned for their flights.

*Ground-recognition trainer.*—The ground-recognition trainer (fig. 10–1(n)) consisted of a prototype molded couch, an actual Mercury periscope, a back-projection screen, and a motorized slide projector. The slide projector displayed a colored, moving image of the earth on the screen. No cloud cover was simulated. The image was viewed through the periscope, located at the proper distance from the screen to simulate the geometry of a periscope in a Mercury spacecraft at 110 nautical miles altitude and aimed at the earth's nadir.

The purpose of the trainer was to familiarize the astronauts with the wide-angle optics of the periscope which caused a compression of the images of coastlines, rivers, mountain ranges, and other topographical features. This trainer was not used extensively because, to a certain degree, the scenes viewed were very similar to those that were seen through the periscope simulation of the ALFA trainer.

*Air-lubricated free-attitude trainer.*—The air-lubricated free-attitude trainer (ALFA) (fig. 10–1(d)), was designed and developed by engineers of the NASA Manned Spacecraft Center. This trainer moved on an air-bearing and had 360° of freedom in roll and 35° of freedom in pitch and yaw. The astronaut operated compressed air jets through a Mercury hand controller. Retrofire disturbance torques were also simulated with compressed-air jets.

Two attitude-control systems were simulated on ALFA: manual proportional and fly-by-wire. In the fly-by-wire simulation, only the low-torque jets (used for attitude control in orbit when attempting to minimize fuel consumption) were simulated. All three reference systems are provided. The periscope was simulated through a wide-angle lens and a system of mirrors which presented a view of a circular screen on which a map of the earth was projected from a film strip. The actual Mercury gyro package and instrument display were mounted on the trainer. The window display was simulated schematically by an illuminated strip to represent the horizon and small bulbs to simulate the stars.

*Multi-Axis Spin-Test Inertia Facility Trainer.*—The Multi-Axis Spin-Test Inertia



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Facility (MASTIF) trainer, created in February 1960 by personnel of the NASA Lewis Research Center, was utilized for a simulation training program of recovery from tumbling flight in February 1960. The trainer (fig. 10–1 (i)) consisted of a couch mounted inside three gimbals, a three-axis hand controller, and a rate display. The astronauts were spun at rotational rates of about 30 rpm about all three spacecraft axes simultaneously. At a prearranged time, the astronauts assumed control of a three-axis compressed nitrogen fly-by-wire attitude control system and brought the couch to rest by reference to a Mercury rate-indicator instrument.

The purpose of the trainer was to provide the best technique and improved confidence level for stopping inadvertent tumbling of the Mercury spacecraft. The training was considered valuable even though the possibility of its application was thought to be fairly remote.

#### Centrifuge Training

Four formal centrifuge programs were conducted at the Aviation Medical Acceleration Laboratory's centrifuge at the Naval Air Development Center at Johnsville, Pa., as part of the group training program (fig. 10–1(c)). The first two programs were combined engineering-feasibility and preliminary astronaut-familiarization programs while the last two were intensive operational training programs for the Redstone and the Atlas flights. The configuration of the centrifuge gondola and the computer control system varied between programs. The gondola was configured to simulate spacecraft for either orbital or ballistic missions. The simulated attitude control system was run closed loop and the centrifuge was run open loop. The astronauts wore full pressure suits and some runs were made at a simulated altitude of 28,000 feet.

Overall, the astronauts experienced an average of 45 hours on the centrifuge. These programs appeared to be extremely valuable both for training and in providing an opportunity for checking out items of personal equipment and for demonstrating the adequacy of the spacecraft instrumentation for viewing under acceleration.

#### Environmental Familiarization

Despite the general familiarity of the astronauts with the space flight environment and their demonstrated capability of performing effectively under stress, an attempt was made during the training program to provide additional familiarity with this environment. The following five requirements were thought to be conducive to good performance under space-flight conditions:

(1) The astronauts required a detailed knowledge of and confidence in the equipment which they had to operate in space. This was primarily provided through the systems training described previously. However, the environmental familiarization involving pressure chamber and centrifuge runs provided an opportunity to become more fully acquainted with the pressure suit, the couch and restraint systems, the bioinstrumentation and other items of personal equipment and to develop confidence that these items would perform their functions adequately in the space-flight environment.

(2) The astronauts also required a familiarity with the environment itself. Familiarity with the conditions of space flight minimizes the number of novel and possibly distracting stimuli which will be encountered in flight. Experience with these conditions also permits the development of the specific techniques for minimizing these environmental effects. For example, under acceleration it is necessary for the astronauts to learn a special breathing technique to minimize the tendency of peripheral vision to become blurred because of reduced oxygenation of the blood. During early training, this breathing technique required some thought and distracted the astronauts from their control tasks. However, as training progressed, the breathing became automatic and full attention could be devoted to the task.

The accommodation of the pilot to the effects of acceleration can be seen in figure 10–3 which

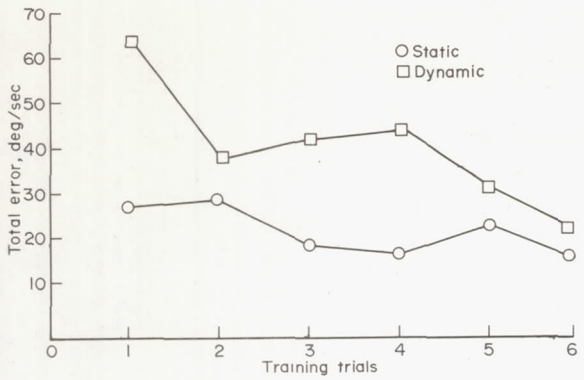



FIGURE 10–3.—Centrifuge retrofire training.

provides a comparison of the retrofire attitude control performance, under the simulated acceleration of the retrorockets and statically. The data presented are average values for all astronauts and show an increase in error with acceleration; however this initial effect tended to disappear with practice.

Table 10–IV summarizes the environmental conditions which were simulated during the group training program. The first column lists the various conditions experienced while the second gives the intensity of exposure encountered in suborbital and orbital flights. The third column summarizes the level experienced in training while the final column lists some of the trainers which were used to provide this experience. With the exception of weightlessness, all the environmental conditions were simulated during training at least to the level expected in a normal flight. Weightlessness condition cannot be simulated within the atmosphere for more than 60 seconds; however, the astronauts did, over several runs, build up an average of 40 minutes total weightlessness per man. In general, all of the environmental familiarization experiences were of value. However, with the exception of the linear acceleration experienced on the centrifuge and effects of suit pressurization, none of the environmental simulations were critical, including weightlessness.

*Table 10–IV.—Flight and Trainer Environment Summary*

| Condition | Level in Flight | | Level Experienced in Training | Simulator |
|---|---|---|---|---|
| | Normal | Emergency | | |
| | Redstone/Atlas | | | |
| Weightlessness | Redstone, 5 min<br>Atlas, 4½ hr | | Up to 60 sec. Average of 40 min total weightlessness. | F–100F, C–131B, and C–135 aircraft. |
| Acceleration | Redstone, up to 11g<br>Atlas, up to 7g | Up to 20g | All normal Atlas and Redstone Profiles and abort profiles up to 16g. Average of 70 dynamic runs per man. | Centrifuge. |
| Reduced pressure | 5 psi for from 4½ hr to 34 hr | Pressurized 4.6 in suit. | Up to 6 hours in pressure suit; up to 3 hours in orbit condition; launch and reentry profiles have been experienced in at 5 psi and in pressurized suit. | Environmental simulator Centrifuge. |
| Heat | Capsule inner wall 275°, post-recovery period at 85°, 35 percent humidity. | | Heat pulse up to 260° with normal recovery period. | Environmental simulator. |
| Rotation (Disorientation) | 10°/sec | | Up to 60 rpm | ALFA trainer; Pensacola rotating room. |
| Tumbling | None | | Up to 54 rpm | MASTIF. |
| High Levels $CO_2$ | Below 0.04 percent | Up to 3.5 percent. | Slow buildup to 3.5 percent | Submarine environmental tank. |
| Noise and Vibration | 150 db outside spacecraft,<br>130 db inside spacedraft,<br>110 db at ear | | 90 to 110 db for normal Atlas launch period. | Centrifuge, Langley, Noise tests. |

(3) A high level of physical conditioning was also required. Since, to meet flying requirements, the trainees had been maintaining themselves in good condition for a number of years, no formal group physical training program was initiated aside from a short period of instruction in scuba diving. Reliance was placed on each individual to keep himself in good physical condition and he was aided in monitoring his conditions by frequent physical examinations and by his own observations of his ability to perform adequately on the centrifuge and in other types of environmental training.

(4) A fourth requirement was the detailed planning and practice of emergency procedures until they could be rapidly and correctly executed. The majority of this type of training occurred on the procedures trainer, particularly during the period just prior to the flight.

(5) A final requirement for performing effectively under stress was to maintain their habits of altertness and their ability to react rapidly and think effectively in emergencies, which they had developed during their careers in flying. Since none of the training situations involved any significant amount of hazard, it was important that the astronauts have an opportunity to maintain their skills in meeting real emergencies. As a result they were provided with aircraft so they could maintain their flying skills (See fig. 10–1(b)).

Through these five steps, knowledge of the equipment available to their use, familiarity with the environment, physical conditioning, preplanning for emergencies, and the habit of constant alertness and readiness for action, the astronauts were provided with the basis for a high degree of effectiveness in performing well under the unusual environmental conditions associated with space flight.

In considering the problems of preparing individuals for performing effectively in a realistic environment, it is interesting to note that a number of programs, in which it was intended to use actual hardware in real environments in order to train the astronauts, were considered but were not put into practice because the training value appeared to be too small to justify the cost or safety hazards involved in their implementation. At the initiation of the Mercury program, it had been recommended that as part of the training program a series of balloon flights be undertaken in which the actual Mercury spacecraft would be carried to altitudes of from 80,000 to 100,000 feet. The plans for this program were carried for several months and the requirements studied in detail. The studies indicated that training value did not justify the risk or the cost involved in the program. Two other programs of a similar nature were also eliminated. One program involved placing the actual spacecraft on the Lewis MASTIF device for training in controlling attitude during retrofire. The MASTIF device was inside a full-scale wind tunnel, which could have been depressurized. Analysis also showed that it would be very difficult to reproduce the conditions of motion typical of space flight because of the very high inertia of the MASTIF gimbals. A final program of the same sort was a plan to place a flight Mercury spacecraft on top of the Redstone launch vehicle during static firing so that the astronaut could experience the actual noise and vibration typical of launch. Once again neither the risk nor the cost appeared justified in view of the limited training value. These three examples illustrate what seems to be a basic result of the Mercury training experience. Using actual flight equipment in simulated environments for training purposes alone generally involves too great an expense to be worthwhile. When only training is involved, mission simulators are most efficient. On the other hand, in the Mercury program, valuable training was achieved during the launch checkout of the actual flight vehicle in the pressure chamber at Cape Canaveral. In this case, however, the simulation benefited not only the training program but the checkout of the flight article.

#### Egress and Survival Training

The astronauts were provided with several training programs designed to prepare them to egress successfully, survive and be recovered under various contingency conditions. The egress and survival programs are summarized as follows.

*Egress training, phase 1.*—The first egress training program was conducted in February 1960, in which the egress trainer, spacecraft no. 5, (fig. 10–1(j)) and the NASA Langley Research Center Hydrodynamic Basin no. 1 were

used. Each of the astronauts made several egresses through the top hatch with and without the pressure suits in calm water and in artificially generated waves up to 2 feet in height.

*Egress training, phase 2.*—The first full-scale open water egress program was conducted in the Gulf of Mexico near the Pensacola Naval Air Station in March and April of 1960. This program consisted of 1 day at sea, during which both top and side hatch egresses were accomplished, and a second day at the training tank for water-survival technique and drill.

*Egress training, phase 3.*—Underwater egress was accomplished at NASA Langley Research Center in August 1960, with the Langley Research Center Hydrodynamic Basin No. 1 again being used. Each astronaut made six egresses while the spacecraft was submerged. Half of these were accomplished while wearing the Mercury pressure suit.

Periodically, the astronauts were given refresher courses on proper egress and recovery procedures through briefings and participation in subsequent egress and recovery exercises.

In addition, each designated flight crew participated in a full-scale recovery exercise prior to each flight during which both top and side egress, survival equipment deployment, and helicopter pickup operations were accomplished.

*Survival training, phase 1.*—Water survival training was accomplished in conjunction with most of the water-egress programs and through briefings. The first water-survival training program was conducted at Pensacola, Florida, in March 1960. The training consisted of several briefings, a training film, and actual practice with the use of the survival equipment in the training tank and in the open sea during egress and recovery operations.

*Survival training, phase 2.*—In July 1960, the Mercury astronauts completed a 5½-day course in desert survival at the Air Force Survival School, Stead Air Force Base, Nevada. The course consisted of three phases: (1) 1½ days of academics oriented to survival operations in the North African or Australian desert; (2) 1 day of field demonstrations covering the utilization and care of available clothing and spacecraft and survival equipment; and (3) 3 days of remote-site training during which the astronauts applied the knowledge and techniques that they had learned during the briefings and demonstrations.

### Preflight Preparation

Approximately 3 months prior to each flight, the designated pilot and his backup began specific preparations for the mission. The period of preparation was, however, somewhat variable depending upon the particular mission and the time between missions permitted by the flight schedules. Pilots participating in the earlier missions had the advantage that the training received in the group program was fresher and that less change had occurred in the vehicle configuration between the time of this program and their flight. Those participating in later flights experienced a lapse of intensive training from 1 to 2 years and had the problem that the spacecraft configuration had changed considerably in the interim, particularly as the mission length was extended. Thus, the preflight period of training became more and more significant. The final impression developing out of the Mercury experience was that on a day-for-day basis preflight preparation was the most valuable period of the training program. Experience indicated that the pilot was required to put in a 10- to 12-hour day for at least 6 days a week during this preflight period. Astronaut Cooper's activities during this time are shown in table 10–V. Since there were so many demands upon the pilot's time, a definite danger existed that important items of training would be pushed aside or overlooked unless care was taken to plan carefully in advance, and frequent training reviews were held to assure that all critical training items had been accomplished. During this period there are five major preparation activities for the flight crew. These activities have been described previously by Astronaut Carpenter (ref. 13).

*Table 10–V—MA–9 Pilot Preflight Activities From January 1, 1963 to Launch Date*

| Date | Day | Activities |
|---|---|---|
| Jan. 2 | Wed | Altitude Chamber Systems Test Review, blood-pressure checkout in altitude chamber, flying (TF–102A) |
| Jan. 4 to 7 | Fri. to Tues | Altitude Chamber Systems Test |
| Jan. 10 | Thurs | Flight-plan review, flying (TF–102A) |
| Jan. 12 | Sat | TV systems test, flying (TF–102A) |
| Jan. 18 and 19 | Fri. and Sat | Morehead Planetarium (celestial review) |
| Jan. 21 | Mon | Weight and balance |
| Jan. 22 | Tues | Systems briefings (ASCS and RCS) |
| Jan. 23 | Wed | Systems briefings (communications and sequential) |
| Jan. 24 | Thurs | Flight-plan and experiments review |
| Jan. 25 | Fri | Systems briefings (electrical and ECS) |
| Jan. 30 | Wed | Flying (F–102A) |
| Jan. 31 | Thurs | Flying (T–33A) |
| Feb. 1 | Fri | Launch vehicle rollout inspection |
| Feb. 2 | Sat | Flying (T–33A) |
| Feb. 3 | Sun | Flying (T–33A) |
| Feb. 4 | Mon | Experiments status review |
| Feb. 5 | Tues | Flight-plan review |
| Feb. 6 | Wed | Couch fitting |
| Feb. 7 | Thurs | Flying (T–33A) |
| Feb. 8 | Fri | Observation of flashing beacon on T–33A |
| Feb. 11 | Mon | Flight-plan briefing to Deputy Director for Mission Requirements |
| Feb. 12 | Tues | Flying (F–102A) |
| Feb. 20 | Wed | Flying (F–102A), flight-food testing |
| Feb. 21 | Thurs | Experiments briefings |
| Feb. 23 | Sat | Flying (T–33A) |
| Mar. 1 | Fri | TV systems test |
| Mar. 4 | Mon | Communication systems radiation test |
| Mar. 6 | Wed | Weight and balance |
| Mar. 8 | Fri | Flying (F–102A) |
| Mar. 12 | Tues | Couch fitting |
| Mar. 13 | Wed | Flying (T–33A, F–102A) |
| Mar. 14 | Thurs | Communication systems radiation test |
| Mar. 15 | Fri | Communication systems radiation test, Mercury Procedures Trainer |
| Mar. 19 | Tues | Darkness and egress test |
| Mar. 20 to 24 | Wed. to Sun | Simulated flight (Hangar) |
| Mar. 24 | Sun | Flying (F–102A) |
| Mar. 26 | Tues | Flying (T–33A) |
| Mar. 27 | Wed | Flying (T–33A), Mercury Procedures Trainer |
| Mar. 28 | Thurs | Flying (T–33A), Centrifuge—acceleration refamiliarization |
| Mar. 29 | Fri | Mercury Procedures Trainer |
| Apr. 1 and 2 | Mon. and Tues | Mercury Procedures Trainer |
| Apr. 4 | Thurs | DOD–NASA MA–9 Review, Prepad RCS test |
| Apr. 5 | Fri | Mercury Procedures Trainer, flying (TF–102A), Morehead Planetarium (Celestial review) |
| Apr. 6 | Sat | Morehead Planetarium (Celestial review) |
| Apr. 7 | Sun | Flying (F–102A) |
| Apr. 9 | Tues | Flying (F–102A) |
| Apr. 10 | Wed | Egress and recovery training |
| Apr. 11 | Thurs | Egress and recovery training, survival pack exercise |
| Apr. 15 | Mon | Flying (F–102A) |
| Apr. 16 | Tues | Mercury Procedures Trainer, mission and flight controller briefing |
| Apr. 17 | Wed | Mission and flight controller briefing |
| Apr. 18 | Thurs | Alinement, weight, and balance; Mercury Procedures Trainer |
| Apr. 19 | Fri | Mercury Procedures Trainer |

*Table 10–V—MA–9 Pilot Preflight Activities From January 1, 1963 to Launch Date*—Continued

| Date | Day | Activities |
|---|---|---|
| Apr. 22 | Mon | Mechanical mate |
| Apr. 23 | Tues | Simulated flight no. 1 |
| Apr. 24 | Wed | Electrical mate |
| Apr. 25 | Thurs | Mercury Procedures Trainer |
| Apr. 27 | Sat | Mercury Procedures Trainer |
| Apr. 29 | Mon | Yaw demonstration (AF Hangar) |
| Apr. 30 | Tues | Systems briefings (review) |
| May 1 | Wed | Systems and operations examination |
| May 2 | Thurs | Launch simulation, Mission Rules review |
| May 3 | Fri | Examination questionnaire review, marked spacecraft's normal and emergency instrument limits |
| May 4 | Sat | Launch simulation |
| May 5 | Sun | Flying (TF–102A) |
| May 6 | Mon | Flight configuration sequence and aborts |
| May 7 | Tues | Network simulation, Flight Plan Procedures training |
| May 8 | Wed | Launch simulation and RF compatibility tests |
| May 9 | Thurs | Network simulation |
| May 10 | Fri | Simulated flight no. 3, flying (F–102A) |
| May 11 | Sat | Mission Status Review, flight-plan and experiments briefings |
| May 12 | Sun | Network simulation, physical examination |
| May 13 | Mon | Mercury Procedures Trainer, mission review |
| May 14 | Tues | Countdown (canceled) |
| May 15 | Wed | Launch |

**Integration of the Pilot and the Spacecraft**

After the spacecraft had been delivered to the launch site, a primary opportunity was provided for the pilot to operate the actual controls of the spacecraft. The participation of the MA–9 pilot with the checkout activities of the spacecraft is listed in table 10–VI(a) and a summary of the time spent in the actual spacecraft of all

*Table 10–VI.—Pilot Time in Spacecraft During Hangar and Launch Complex*

*(a) MA–9 Pilot Time in Spacecraft 20*

| Date | Test description | Duration, hr:min |
|---|---|---|
| Oct. 11 to 19, 1962 | Integrated systems tests | 06:45 |
| Nov. 11, 1962 | RCS–hangar | 03:15 |
| Jan. 5, 1963 | Altitude chamber | 06:45 |
| Jan. 12 and Mar. 1, 1963 | TV systems test | 07:00 |
| Mar. 4, 14, 15, 1963 | Communications systems radiation test | 04:45 |
| Mar. 19, 1963 | Darkness and egress | 01:20 |
| Mar. 20, 21, 22, 1963 | Simulated flight, hangar | 12:10 |
| April 4, 1963 | Prepad RCS test | 00:50 |
| April 18, 1963 | Alinement, weight, and balance | 04:00 |
| April 23, 1963 | Systems test and simulated flight no. 1 | 04:00 |
| April 24, 1963 | Electrical mate | 04:30 |
| May 3, 1963 | Mark instrument normal and emergency limits | 00:45 |
| May 6, 1963 | Flight configuration sequence and abort | 03:00 |
| May 8, 1963 | Launch simulation and RF compatibility | 05:00 |
| May 10, 1963 | Systems test and simulated flight no. 3 | 03:45 |
| May 14, 1963 | Countdown (canceled) | 06:00 |

*Table 10–VI.—Concluded.*

(b) *Approximate Time in Flight Spacecraft During Preparation Periods for Each Orbital Flight*

| Flight | Time, hr |
|---|---|
| MA–6 | 25:55 |
| MA–7 | 45:00 |
| MA–8 | 31:27 |
| MA–9 | 73:50 |
| Average | 44:03 |

the orbital pilots is given in table 10–VI(b). This activity is essential, since:

(1) An opportunity was provided to make final adjustments of personal equipment, such as the pressure suit, survival equipment, food items, and check lists to satisfy the special requirements of the flight spacecraft and the pilot.

(2) These tests provided an opportunity to check out the spacecraft system with the man in the loop; thus, for example, the adequacy of the environmental control system was checked with the pressure drop resulting from the pilot in his suit.

(3) The pilot became familiar with the specific configuration and performance of his spacecraft. The settings for the cooling system or the feel characteristics of the control systems vary slightly from spacecraft to spacecraft, and the pilot had an opportunity to become familiar with these features of the vehicle he would fly.

(4) The pilot had an opportunity to gain further familiarity with the prelaunch checkout procedures on the launch pad. During this time, he learned his role in the countdown and became familiar with the instrument indications and the lights and sounds that accompany the various tests as the vehicle is readied for flight.

**Systems Training**

A second major area of activity of the astronauts during this period was in systems training for his spacecraft. This systems training began with one or more series of lectures by the engineers involved in the checkout of the vehicle. Each lecture covered a specific system in great detail, emphasizing operational techniques and functional interrelationships. These systems lectures were then followed by extensive practice in emergency procedures on the Mercury procedures trainer. A problem was encountered in modifying the Mercury procedures trainer no. 2 to keep it as close as possible to the configuration of each spacecraft. It was, of course, impossible to make them completely identical. However, in general, it was possible to alter the trainer so that as the spacecraft systems were modified, the changed performance would be reflected to the pilot during simulations. When modifications could not be made, it was extremely important to make the pilot aware of the differences between the trainer's operation and the flight operation so that he could keep them clearly in mind.

Table 10–VII(a) summarizes the MA–9 pilot's training on Mercury Procedures Trainer no. 2 whereas table 10–VII(b) shows the total amount of time spent on the Mercury procedures trainer by the pilots of the four orbital missions during their preflight training program. Also indicated in table 10–VII(b) are the numbers and categories of malfunctions experienced. These data give some indication of the amount of time devoted to recognition and correction of the many malfunctions which could be programed into the trainer. The relative emphasis to be placed on emergency procedures in comparison with normal mission activities is difficult to assess. This seems to be a characteristic which may be increasingly true in the future, since a major function of the man may be to correct malfunctions of the vehicle's systems.

*Table 10–VII.—Summary of Time Spent on MPT No. 2 During Preflight Preparation Period*

(a) *MA–9 Pilot*

| Date, 1963 | Type of training | Time, hr:min | Number of simulated missions | Number and type of simulated missions | | | | | | Special training activities [a] |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ECS | RCS | Sequential | Electrical | Communications | Other | |
| Mar. 15 | Flight checklist review | 02:15 | 4 | | | | | | | 1, 3, 4 |
| Mar. 27 | Attitude control practice | 01:45 | 1 | | | | | | | 1, 4 |
| Mar. 29 | Simulated systems failures | 02:30 | 8 | 3 | 2 | 4 | 3 | 1 | 1 | 1, 2, 3, 4 |
| Apr. 1 | Simulated systems failures | 02:30 | 5 | 2 | | 5 | 2 | 1 | 1 | 1, 2, 3 |
| Apr. 2 | Simulated systems failures | 02:00 | 3 | | 2 | 5 | 1 | | | 2, 3 |
| Apr. 5 | Simulated systems failures | 01:30 | 2 | 2 | | 2 | | 1 | | 2, 3 |
| Apr. 18 | Simulated systems failures | 02:15 | 4 | 2 | 1 | 4 | 4 | | 1 | 1, 2, 3 |
| Apr. 19 | Simulated systems failures | 03:45 | 6 | 1 | 1 | 4 | 3 | 1 | 1 | 2, 3, 5 |
| Apr. 25 | Flight-plan activities | 02:00 | 2 | 1 | | | | | | 1, 4 |
| Apr. 27 | Simulated systems failures | 01:30 | 3 | | 1 | 1 | 1 | 1 | | 1, 2, 3 |
| May 2 | MCC–BDA simulation | 01:30 | 2 | | | 2 | 1 | | | 2, 3 |
| May 4 | MCC–BDA simulation | 01:30 | 2 | 2 | | 1 | 1 | | 1 | 2, 3 |
| May 7 | Network simulation and flight-plan activities. | 05:00 | 2 | | | | | | | 1, 4, 5 |
| May 9 | Network simulation | 01:00 | 2 | | | | | | | 1 |
| May 12 | Network simulation | 01:00 | 1 | | | 1 | | | | 1 |
| May 13 | Simulated systems failures | 01:30 | 5 | | 1 | 3 | 1 | | 1 | 1, 2, 3 |
| Total | | 33:30 | 52 | 13 | 8 | 32 | 17 | 5 | 6 | |

[a] The column numbers refer to the following activities:
1—Normal launches and reentries
2—Launch aborts
3—Orbital and reentry emergencies
4—Retrofire or reentry attitude control
5—Flight-plan activities

*Table 10–VII.—Concluded*

*(b) Four Orbital Pilots*

| Flight | Number of Missions | Total Hours on MPT no. 2 | Number and type of failures | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | ECS | RCS | Sequential | Electrical | Communication | Other |
| MA–6 | 80 | 59:45 | 30 | 24 | 57 | 35 | 11 | 25 |
| MA–7 | 73 | 70:40 | 24 | 11 | 43 | 26 | 7 | 32 |
| MA–8 | 37 | 29:15 | 10 | 5 | 22 | 15 | 5 | 11 |
| MA–9 | 52 | 33:30 | 13 | 8 | 32 | 17 | 5 | 6 |
| Average | 60 | 48:35 | 19 | 12 | 38 | 23 | 7 | 18 |

**Flight Plan Development and Training**

The pilot also participated in the development and practice of a mission flight plan, which varied considerably in each mission. (See paper 17.) The astronaut participated in this process to help insure that he adequately understood the requirements and that the specific procedures could be carried out without compromising other mission requirements. The flight plan activities were tried out in the Mercury procedures trainer to determine the best procedures and equipment configurations. Since it was highly desirable to give the pilot ample opportunity to practice the flight plan and to get experience with the experimental equipment prior to the flight, it was essential to finalize the flight plan and have the experimental equipment ready well ahead of the launch date.

In addition to the practice of the specific mission activities in the Mercury procedures trainer, a number of special refresher training activities were conducted. Normally, each of the flight crews received a short refresher training program on the centrifuge. In this program no attempt was made to provide a complete simulation of the Mercury instrument panel or control tasks. The pilots normally experienced from six to eight launch or reentry profiles in the centrifuge to help refresh them in their breathing and straining techniques.

The flight crews also normally received a planetarium indoctrination (fig. 10–I(h)) to help them review the celestial sphere as seen from orbit. Since these programs were held close to the flight date, it was normally possible to simulate the appearance of the sky on the actual day of the launch and to simulate some of the special astronomical phenomena to be observed during the flight.

**Combined Astronaut-Flight Controller Training**

A fourth area of training conducted during the preflight period was the combined training of the astronaut with the flight control groups. For this training the Mercury procedures trainer no. 2 was tied into the Mercury Control Center's simulation equipment so that the astronaut could communicate directly with the flight controllers and the vehicle parameters from the Mercury procedures trainer no. 2 would be displayed to the flight controller in the same form as the vehicle data during the flight. Two types of training runs were made. The first was the launch-emergency training sessions in which only the launch portion of the mission was simulated. Various types of emergencies were simulated, some affected the astronaut but most involved information displayed to the controllers. During this time the astronaut and the ground flight controllers had an opportunity to become familiar with each other's procedures and to refine the launch communications and emergency procedures. Following each run, a debriefing session would be held to critique the run and to modify any procedures which did not appear adequate.

Following the launch abort simulations, network simulations were run with the flight controllers. On these simulations the pilot, through the hardline, could be in direct communication not only with the launch control center but with the other flight-control sites in the United States and Australia. In

these simulations the pilot would frequently take part, thereby providing some of the stations with an opportunity to become familiar with his particular voice and communication patterns. This was particularly significant for the medical monitors since they made use of voice communications as one of their major monitoring aids. While these sessions were highly valuable for the flight controller, they were less valuable for the astronaut since much of his time would be spent with the spacecraft in the orbital configuration with little or no opportunity to practice emergency procedures. As a result, the astronaut frequently went through a launch and perhaps one-orbital pass with the network simulation and then spent the rest of his time in the simulator, carrying out emergency procedures and other special activities in which he particularly needed practice.

### Medical and Physical Preparation

A final area of activity during this preflight period was in the medical and physical preparation of the astronaut. During this period, the final physical examinations, establishing the fitness of the pilot for the flight, were given and the majority of the baseline data with which the inflight results would be correlated was collected. It was also during this period that the astronaut was placed on a special diet in order to prevent possible solid waste problem during the flight. Medical preparations for the flight are described in greater detail in paper 11.

During this preflight period each of the astronauts intensified their physical fitness program, bringing it to a peak shortly before the launch date. This physical activity was important not only in insuring a high level of fitness at the time of launch but it also served the purpose of giving the pilot an opportunity to relax from the pressing technical problems which occupied the majority of his day. Overall, the problem of maintaining good physical fitness and avoiding excessive fatigue during this period was a serious one.

Concern was expressed in some quarters that the repeated delays which often occurred in the launch date would produce anxiety in the pilot or result in a letdown in profficiency due to "over training" or loss of motivation. No such effects were noted with any of the pilots. Astronaut Glenn experienced the longest delay following a launch attempt (30 days) with no undesirable effects either by his own account (ref. 14) or as indicated by his trainer performance. His performance on the retrofire control task for the month before and after the postponement of his flight is shown in figure 10–4. As

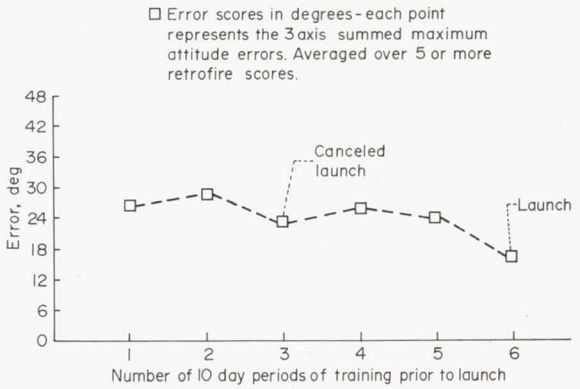



FIGURE 10–4.—Procedures trainer retrofire attitude control scores. MA–6 pilot.

can be seen there is no evidence of decrement in performance following the postponed launch.

### Training Evaluation

The inflight performance of the pilot provides the best indication of the adequacy of the astronaut training program. Further verification was provided by comparing performance of specific maneuvers during flight with those on the trainers, and by having the pilots' comment on the value of the various training devices.

In those cases where specific flight maneuvers were practiced on the procedures trainer, comparisons can be made between the attitudes held in the trainer and those maintained in flight. This has been done in all previous flight reports in the sections on pilot performance (refs. 15 to 19). However, the number of these comparisons is limited since many periods of manual maneuvering could not be compared with ground data because the specific maneuver carried out during flight was not practiced under controlled conditions or because the maneuver involved attitudes outside the limits of the autopilot sensing system, in which case, attitude data would not be available from the gyro indicators.

A great deal of evaluative material was obtained from the astronauts during the debrief-

ings following each mission. In general, the astronauts reported that while weightlessness was generally pleasant, there was a short period during the flight when they felt that they needed some time to adapt to both the weightless experience and to the novel view through the spacecraft window. (See paper 20.) Both of these features of the space flight were inadequately simulated during the training periods since the weightless condition could not be simulated for more than a minute and, until late in the program, there was no dynamic simulation of the view through the Mercury spacecraft window. This adaptation period, to the orbital flight condition, might have been reduced had it been possible to have a simulation of the external view and more prolonged weightless experience. In any case, this small adaptation period was not a serious problem for any of the astronauts.

The pilots were unanimous in indicating the importance of their participation in the checkout of the spacecraft during the period just prior to the flight. Many of them felt that this was the most valuable single portion of the training program. All of the pilots felt that the procedures trainer was the single, most useful training device. However, there were variations among them in the opinions of the amount of time required on the trainer prior to the flight. There was also general agreement that the centrifuge was the most critical environmental simulation device and that a short refamiliarization experience on the centrifuge prior to the flight was highly desirable.

The Mercury flight program was too limited to evaluate in detail all the many training devices and programs which were used in the astronaut training program. However, the best estimate of the authors as to the relative utility of the various trainers and programs are indicated in Table 10–I in the last column. In considering these ratings, the reader should note that they apply to programs with the special features of the Mercury training program listed in the introduction to this section. In addition to these ratings, the following general conclusions appear warranted:

(1) The devices and programs used in the Mercury astronaut training program were adequate to provide transition training for skilled pilots to the operation of a spacecraft.

(2) The program could have been shortened and made more efficient had adequate training facilities been available at the initiation of training and in one location.

(3) The most important environmental factors requiring simulation during the training were linear acceleration and the reduced mobility produced by the pressurized suit.

(4) Other environmental simulations were desirable but not critical to adequate flight preparation. This conclusion includes the weightless experience. However, it should be noted that training in weightlessness was relatively unimportant in the Mercury program because the astronaut was unable to move from the seat.

(5) Simulations involving actual flight hardware in realistic environments were studied and generally found to involve more cost and risk than could be justified by their training value, unless they were required for vehicle checkouts.

(6) Experience in the actual vehicle to be flown prior to the flight is a highly essential feature of the preflight preparation and is an exception to the foregoing generalization.

(7) Flight plans and all experimental and other movable equipment items which will be used within the spacecraft must be available and finalized well in advance of the launch date in order to permit adequate time for training in their use.

(8) A fixed-based simulator with dynamic displays is generally adequate for orbital flight training since angular and linear acceleration cues are relatively insignificant in the weightless condition. However, in certain cases motion may simplify the simulation problem.

(9) Two simulators are necessary in order to support both the general group training program at the central site and the preflight preparation program at the launch site.

(10) External view simulation on the full-mission simulator is essential since much of the orbital maneuvering will be done with the external view used as a reference.

(11) Integrated flight crew-flight controller training is essential to refine mission rules and communication procedures.

(12) Flexibility in the design of all trainer systems is essential in order to permit modification to fit the particular configuration of each flight vehicle.

## References


1. Voas, Robert B.: *A Description of the Astronaut's Task in Project Mercury.* Human Factors Journal, vol. 3, no. 3, June 1961, pp. 149–165.
2. Slayton, D. K.: *A Pilot's Look at Project Mercury.* Paper given to the Society of Experimental Test Pilots. Oct. 9, 1959.
3. Wilson, C. L., ed.: *Project Mercury Candidate Evaluation Program.* Wright Air Development Center, WADC Tech. Rep. 59–505, Dec. 1959.
4. Ruff, George E., and Levy, Edwin Z.: *Psychiatric Evaluation of Candidates for Space Flight.* Am. Jour. of Psychiatry, vol. 116, Nov. 1959, pp. 385–391.
5. Carp, Abraham, ed.: *Report of the Working Group on Personnel Selection for Man in Space.* Meeting at National Academy Research Council Building, Washington, D.C., Dec. 2–3, 1959.
6. Douglas, W. K.: *Selection and Training of Space Crews.* Lectures in Aerospace Medicine, USAF Aerospace Medical Center, Jan. 11–15, 1960.
7. Slayton, Donald K.: *Pilot Training and Preflight Preparation.* Proc. Conf. on Results of the First U.S. Manned Suborbital Space Flight. NASA, Nat. Inst. Health, Nat. Acad. Sci., June 6, 1961, pp. 11–18.
8. Voas, Robert B.: *Project Mercury Astronaut Training Program.* In Psychophysiological Aspects of Space Flight, Columbia U. Press, 1961, pp. 96–116.
9. Anon.: *Project Mercury Familiarization Manual.* McDonnell Aircraft Corp., SEDR 104, Dec. 1, 1962.
10. Anon.: *Capsule Flight Operations Manual.* McDonnell Aircraft Corp. SEDR.
11. Anon.: *Operational Manual for Manned Satellite Capsule Procedures Trainer.* McDonnell Aircraft Corp. SEDR 115, Book I, Apr. 30, 1960.
12. Voas, Robert B.: *Manned Control of Mercury Spacecraft.* Astronautics, vol. 7, no. 3, Mar. 1962, p. 18.
13. Carpenter, M. Scott: *Astronaut Preparation.* Results of the First U.S. Manned Orbital Space Flight, February 20, 1962. Supt. Doc., U.S. Government Printing Office (Washington, D.C.) pp. 105–111.
14. Glenn, John H., Jr.: *Pilot's Flight Report.* Results of the First U.S. Manned Orbital Space Flight. February 20, 1962. Supt. Doc., U.S. Government Printing Office (Washington, D.C.) pp. 119–136.
15. Staffs of NASA, Nat. Inst. Health, and Nat. Acad. Sci.: *Proceedings of a Conference on Results of the* First U.S. Manned Suborbital Space Flight. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), June 6, 1961.
16. Staff of NASA Manned Spacecraft Center: *Results of the Second U.S. Manned Suborbital Space Flight, July 21, 1961.* Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
17. Staff of NASA Manned Spacecraft Center: *Results of the First United States Orbital Space Flight, February 20, 1962.* Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
18. Staff of NASA Manned Spacecraft Center: *Results of the Second United States Orbital Space Flight, May 24, 1962.* NASA SP–6, Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
19. Staff of NASA Manned Spacecraft Center: *Results of the Third United States Manned Orbital Space Flight, October 3, 1962.* NASA SP–12, Supt. Doc., U.S. Government Printing Office (Washington, D.C.), Dec. 1962.

# 11. AEROMEDICAL PREPARATIONS

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**Summary**

The lessons learned from the operational medical program conducted in Project Mercury are discussed in this paper.

The objectives of the medical portion of the crew selection program were met, and detailed physical examinations on even select test pilot groups have found rejectable defects. Stress-testing has been made part of a selection-in-depth training program.

Medical training given to the astronauts has been of great value during inflight monitoring and discussion of medical problems.

Medical maintenance has included routine medical care, and annual and special physical examinations. Close association of the flight surgeon and the astronaut in training has produced an excellent preventive medicine practice. The flight crew surgeon is best fitted to determine the astronaut's readiness for flight, but a specialist team conducts the examination for baseline data to compare with postflight data. Preflight examinations were conducted before each checkout procedure and more formally at 10 days and 3 days before flight, and on flight morning. Longer missions with Pacific recovery caused modification of the postflight examinations. The importance of practice runs of most of the medical procedures was shown and a medical countdown was developed and integrated with the Mercury Control Center (MCC) and blockhouse countdown.

Complete isolation of the crew is impractical and has depended on a reduction of stronger contacts in the immediate preflight period.

Drugs were provided in injectors, and pills were available in flight and in the survival kit. The only drug used was the dextro-amphetamine sulfate on the MA–9 mission. The astronaut must always be pre-tested to any drug he may use. Scheduling of rest, activities, and exercise periods is necessary. A method of obtaining separate urine samples was successfully used. Dietary control of defecation was successful. Inflight food and water ingestion must be scheduled.

Medical monitoring was performed for flight-safety reasons and for aiding the surgeons in making go–no–go recommendations to the operations director. The value of range flight simulations and of the medical flight controller has been shown. Parameters monitored included body temperature, respiration, electrocardiogram, blood pressure, and voice. The comparison and correlation of readings with environmental data are stressed. Correlation of inflight events and physiological responses is very meaningful. The space-flight environment, while exposing men to numerous stresses, has produced no unmanageable physiological overload. Postflight orthostatic hypotension has been noted for a period of several hours.

Recovery operations have been modified from taking medical care to the astronaut to taking the astronaut to medical care. The support has been trimmed to require fewer highly trained personnel to "wait it out" at the launch site.

Project Mercury gave the opportunity to define more closely the medical problem areas as the future is anticipated with great expectations and confidence in man's ability to adapt to and conquer this new frontier.

## Introduction

The development of an operational medical program for Project Mercury posed a challenge to the national aerospace medical community in line with that which the orbiting of man posed to the national engineering community.

The purpose of this paper is to review briefly and necessarily incompletely the medical operations and findings from all our manned space flights and to emphasize the knowledge ac-

quired which may be applied to future programs. Details of the operational procedures and findings are documented in the several reports of the Mercury missions (refs. 1 to 12).

The nature of the challenge called for the development of some ground rules applicable to the medical aspects. It was determined that:

(1) The simplest and most reliable approach should be used.

(2) Off-the-shelf items and existing technology should be used wherever possible.

(3) Man was being thrust into a truly unknown environment, and his reactions to this environment were relatively unknown.

(4) A direct approach would be taken to the problem areas, and attempts would be made to provide the best protection and monitoring capable within the operational constraints of the mission.

Many lessons have been learned from this first experience of the free world with manned space-flight operations. The responsible medical community had honestly attempted to evaluate potential problems based upon knowledge at that time. In doing this, several possible problems were raised which, it appears, this program has answered to some degree. Weightlessness is a good example of the many barriers to man's entry into space which were raised prior to this program. Some of the dire physiological effects predicted as a result from exposure to this condition and therefore to be limiting to space flight were anorexia, nausea, disorientation, sleepiness, sleeplessness, fatigue, restlessness, euphoria, hallucinations, decreased g-tolerance, gastrointestinal disturbance, urinary retention, diuresis, muscular incoordination, muscle atrophy, and demineralization of bones. It will be seen that few of these remain of concern. Another area in which there were predictions of undesirable effects is in the psychological response to the isolation of space. The astronauts to date have not been isolated in space and have generally complained of too much earth contact. There has been no evidence of any breakoff phenomenon or aberrent psychological reaction of any sort. Thus, while no serious problems have developed, more information is needed on increased time periods in space and the conclusions of the present paper can only be based upon the duration of flights thus far flown. Each mission has been used as a means of evaluating the next step into space, and it is believed that the six manned missions in this program have laid the groundwork for future programs. Project Mercury gave the opportunity to define more closely the medical problem areas, and the future is anticipated with great expectations and confidence in man's ability to adapt to and conquer this new frontier.

### Crew Selection and Training

The medical portion of the selection program had as its objectives the provision of crew members who (1) would be free of intrinsic medical defects at the time of selection, (2) would have a reasonable assurance of freedom from such defects for the predicted duration of the flight program, (3) would be capable of accepting the predictable psycho-physiologic stress of the missions, and (4) would be able to perform those tasks critical to the safety of the mission and the crew. The selection board found themselves viewing already trained test pilots somewhat in the same manner as cadets entering a training program are viewed. Small numbers were selected, leaving little excess for attrition. In view of these objectives, the group was culled by records review, interview, and testing until a final group was given a rigorous medical examination at the Lovelace Clinic in Albuquerque, New Mexico. This examination was followed by a stress-testing program at Wright-Patterson Air Force Base, Ohio. The results of these examinations were reviewed by the participating physicians, and the candidates were given a medical rank order. This rank order was then presented to a board which selected the original seven astronauts. In retrospect, it can be said that the results of this program were adequate in view of the fact that the assigned astronauts have successfully completed their flight missions. This early program has been of assistance in the development of current selection program. The stress-testing in the initial selection efforts has been deleted since it was found to be of little value in a group who had already been very thoroughly stress-tested by virtue of their test-pilot background. Stress-testing has become a part of the training program with a selection in depth carried on during the training. Thus, each exposure is mission-oriented and further is an additional

selection test as well as providing baseline medical information. In the current programs, this technique is being used; and the astronauts understand that they are continually undergoing selection and that there may be attrition.

The premise that detailed physical examinations given to groups as select as test pilots will show up many physical defects which would interfere with a reasonable prediction of career length in the manned space-flight program has been confirmed in this program.

The training program has included a series of lectures on the anatomy and function of the human body, and the series has proven to be of great value during inflight monitoring and discussion of potential medical problems. Every attempt has been made to use engineering analogies where possible and to impress the flight crews with the fact that the human organism and its many systems must be monitored as thoroughly as many of the engineering systems if mission success is to be assured. There has been no formal physical training program but each astronaut has been charged with maintaining his fitness through programed exercise of his choice. A wide variety has been used by the group. Medical advice was offered and the importance of regular training periods was stressed during the preflight preparation period. A plateau should be reached and, although no specific level is specified, it is believed the astronaut is better prepared to withstand the flight stresses if he maintains a state of physical fitness.

### Medical Maintenance and Preflight Preparation

The medical maintenance during this program consisted of the routine medical care similar to that provided specialized groups of aircraft pilots, annual physical examinations, and special physical examinations performed before procedures such as altitude-chamber runs, pressure-suit indoctrinations, and centrifuge runs. The flight schedule with its necessary preflight spacecraft checkout procedures, simulated flights, and launches, frequently exposed each flight crew member to several physical examinations within a given year. An attempt was made to make these physical examinations serve several purposes such as qualifying the individual for his annual physical, being ready to participate in a given procedure, and collecting baseline data. A close and frequent contact between flight crews and flight surgeons, with the flight surgeons monitoring participation in all stress exposures and training exercises, proved to be extremely valuable preparation for the flight mission. This close association also provided excellent preventive medicine practice among the flight crews. It is thought that the flight crews have certainly had no more illness than what would be expected in a routine pilot population; and the general feeling is that there was probably much less.

The preflight physical examinations were to serve two basic purposes. First, they should allow the flight surgeon to state that the astronaut was qualified and ready for flight. Second, they should provide a baseline for any possible changes resulting from exposure to the space-flight environment. The flight crew surgeon appears best qualified to determine whether the astronaut is medically ready for flight. Early in the program, the search for unexpected changes in body systems as a result of exposure to space flight dictated specialty examinations of various body systems. A team was assembled from the Department of Defense and included specialists in internal medicine, ophthalmology, neurology, psychiatry, and laboratory medicine. The same specialties have continued to be represented, but certain items of the examinations have been modified as knowledge of the lack of serious effects of flight on the astronaut was gained. Prior to the selection of a flight astronaut for a given mission, the medical records of those being considered are reviewed in detail and a medical recommendation given to the operation director. Following experience on the early missions, it was determined that a thorough evaluation of the flight astronaut would be made 10 days prior to the scheduled mission to assure management and the flight director that the astronaut was indeed ready for the mission. This examination included a medical evaluation of both the flight astronaut and his backup. Three days prior to the mission, the detailed physical examination was completed by the various medical specialists and the necessary laboratory work was accomplished. On flight morning, following a brief medical examination, a final determination was



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made as to the readiness of the astronaut for flight. This examination was principally concerned with noting any recent contraindications to flight which may have developed. While early in the program other specialists participated in this examination, on the last two missions, the participation was reduced to that by the flight crew surgeon.

The postflight medical examinations were initially made by the Department of Defense recovery physicians stationed aboard the recovery vessel. On the early mission, the astronaut was then flown to Grand Turk Island and was joined there by the team of medical specialists who had made the preflight examination and by the flight crew surgeon. As the flights became longer and recovery was accomplished in the Pacific Ocean, the plan was changed and one of the NASA flight surgeons was predeployed aboard the recovery carrier to do the initial postflight examination and debriefing. On the MA–8 mission, the Director of Medical Operations and the medical evaluation team deployed to the Pacific recovery site several hours after recovery, and this was not only a tiring experience, but necessitated that a great deal of the examination and debriefing be done prior to their arrival. The detailed postflight specialty examination was then conducted at Cape Canaveral when the astronaut returned from the recovery site. In some instances, this practice required the teaching of special techniques to the flight surgeon in order that early information could be obtained. Project Mercury has been most fortunate in having rapid postflight recovery and examination of the flight astronauts, allowing excellent comparison of postflight with preflight data. It would seem from our experience that the retention of any specialty examination team at a mainland launching or debriefing site would be the preferable plan of action.

Early in the preflight preparations, it was determined that there was a need for many practice runs of various procedures. These runs were accomplished by doing the actual flight-type preparation for centrifuge runs, spacecraft checkout runs in the chamber at Hanger S, simulated flights and launches, and procedures trainer exercises. The Mercury-Redstone suborbital flights were also extremely helpful in preparation for orbital flight. A medical countdown was developed with specific timing of the various events and coordination with the blockhouse and range countdown. In order to have no delay in the scheduled launch, a great deal of practice in this countdown was necessary. It has continued to pay dividends in the later missions. Backup personnel in the various medical areas are needed just as backups are needed for the various pieces of equipment. Experience has allowed the number of backup personnel to be kept to an absolute minimum.

Prior to the first launch, consideration was given to the necessity for isolating the flight crew in order to prevent the development of some communicable disease immediately prior to or during flight. It soon became evident, however, that such isolation was impractical in view of the numerous requirements upon the flight crew during the 2 weeks prior to launch. Many activities required the presence and participation of the astronaut, and the isolation was reduced to attempts to curtail the number of contacts with strangers. As the missions get longer and longer, the situation may have to be re-evaluated since the mission could last longer than the incubation period of some diseases. No difficulty was encountered during the Mercury program with the use of only a very modified isolation plan.

One of the basic concepts developed stated that there would be no drugs used as routine measures, but that drugs would be made available for emergency use. Injectors were made available which could deliver their contents through the pressure suit into the astronaut's thigh. During the first four missions, the drugs available in the injectors included an anodyne, an antimotion sickness drug, a stimulant, and a vasoconstrictor for treatment of shock. In the later missions, this was reduced to the antimotion sickness drug and an anodyne, available both on the suit and in the survival kit. An evaluation of the longer mission programed for MA–9 led to the decision to make available tablets of dextro-amphetamine sulfate, both in the suit and in the survival kit. Antimotion sickness and antihistamine tablets were also made available. The astronaut's mental and physical integrity were never in doubt during the mission. As the time for retrofire approached, a review of the mission tasks made

it evident that the astronaut had undergone a long and rigorous work schedule from which he might be expected to experience considerable fatigue, even assuming ideal environmental conditions and full benefit from restful sleep. As has been reported, medication was used for the first time during flight when the dextro-amphetamine sulfate was taken prior to the initiation of retrosequence. Such drugs should be available and plans must be made for their availability both during flight and postflight in the survival kit. The astronaut must always be pretested for effect of the drugs which will be used.

Experience has shown that care must be taken to prevent astronaut fatigue during the final preflight preparations as well as postflight. Many individuals have matters of importance which must be decided by the astronaut during the final week of preparation; and as launch day grows closer, the demands on the astronaut's time increase. Careful scheduling of rest, activities, and exercise periods are needed; and much more attention must be paid to this scheduling in future missions. Since the effects of these variables were unknown, it was the flight surgeon's decision to administer 5 mg of dextro-amphetamine sulfate to the astronaut in order to increase the probability of peak performance during reentry. Experience has shown that 48 to 72 hours is a minimum time for a postflight rest and relaxation following a 34-hour mission. Seventy-two hours should be a minimum for future missions.

Early missions required only simple provisions for the collection of urine and blood samples. The short-mission durations made it entirely feasible to collect all the voided urine in a single container within the suit and to recover it after astronaut recovery. As mission duration increased, this became an unworkable procedure; and further, there was a desire to obtain separate urine samples for analysis. The last mission utilized a system for collecting five separate and complete urine samples for later evaluation. This system worked properly but will require modification for future missions. No blood samples have been obtained during flight. Every attempt has been made to combine the various blood requirements in order to require as few vena punctures as possible both preflight and postflight.

Early in the preparation period, a medical flight plan is developed and integrated with the overall mission flight plan. A good deal has been learned about realistic sampling in light of flight plan and in utilizing normal operational activities and reports as means of medical evaluation.

Dietary control has been utilized for approximately 1 week prior to each mission. The first several days were used to assure a normal balanced diet during the rather hectic preflight preparations. In order to prevent defecation during the mission, the low-residue diet was programed for 3 days prior to launch, and the time extended if the launch was delayed. This diet performed its task very satisfactorily during the entire Mercury program; still, indications are that any more prolonged period would seem unwise. The inflight food has consisted of the bite-size and semi-liquid tube food on the early missions. On the last mission, the freeze-dehydrated food was added. Problems with crumbling have been encountered with the bite-size food, and difficulty in hydrating the freeze-dehydrated food was encountered on the last mission. The assurance of palatable food is necessary, and proper containers and practice in their use appear indicated. It also appears necessary to schedule food and water intake on the flight plan and to check to see that it has been properly accomplished.

### Medical Monitoring

The Mercury program provided the free world with the first opoprtunity for full-time monitoring of man in the space-flight environment. At the start of this program, the continuous monitoring of physiological data from a pilot conducting a mission was a very recent concept. At the time, there were no off-the-shelf items available to allow continuous and reliable physiological monitoring. It was decided to attempt to monitor body temperature, chest movement, and heart action (ECG). Standards required that the sensors and equipment be comfortable, reliable, compatible with other spacecraft systems, and would not interfere with the pilot's primary mission.

It should be realized that the biomedical sensors are used as a means of flight-safety monitoring. The primary purpose is to assist the

monitoring flight surgeon in determining whether the astronaut is capable of continuing the mission from a physiological point of view. The information is used as a basis for making go-no-go decisions in the control center. No attempt has been made under the current operational conditions to perform detailed system evaluation or analysis.

A great deal of experience in medical flight control of an orbiting astronaut was obtained through the use of the many range simulations and the several actual flights. The participation in simulations and in flights prior to those which were manned proved to be extremely valuable training exercises for the actual missions. The medical flight controller has indeed shown himself to be a valuable member of the flight-control team. The development of mission rules to aid in flight control was necessary in the medical area just as in the many engineering areas. It is difficult to establish definite number-value cut-offs for various medical parameters, but this was done early in the program. Gradually, these rules were made less specific so that the evaluation and judgment of the medical flight controller were the prime determinants in making a decision. The condition of the astronaut as determined by voice and interrogation rather than physical parameters alone became a key factor in the aeromedical advice to continue or terminate the mission. This is as it should be and follows the lessons which were learned in general medicine wherein numerical laboratory values are not necessarily the final answer. Trend information as shown by at least three stations was shown more reliable than single values. In developing the flight-control philosophy prior to the first manned flight, it was thought that it would be necessary for the flight surgeon to talk directly to the astronaut very frequently in order to evaluate his physiological state. As operational experience was gained, it became obvious that this was not the case. Information inquiries were passed easily and smoothly through the spacecraft communicator with the flight surgeon retaining the privilege of talking directly should the need arise. It was also thought early in the program that the occurrence of most any medical emergency in flight would require an early or even a contingency landing. Again, as operational experience was gained with the range and with the planned recovery operation, it was determined that the best philosophy was one which held that the astronaut was in a very fast, air-conditioned ambulance on 100-percent oxygen and in most instances it would be better to return him in the spacecraft to a planned recovery area rather than to abort the flight in a contingency area where it might take hours or days to recover him.

The physiological parameters monitored and the sensor changes and problems may be summarized in the following manner. Body temperature was monitored in all missions through MA–9 with a rectal thermistor. Rectal temperature was found to be the most reliable measurement. The long duration of the last flight and a desire for more comfort resulted in this thermistor being modified for oral use. The range of the thermistor was also changed, so that when it was in the stowed position on the right ear muff it would record suit-outlet temperature. It worked very satisfactorily in this manner.

Respiration was at first measured by an indirect method by using a linear potentiometer and carbon-impregnated rubber. This method was changed early in the program to a thermistor kept at 200° F and placed on the microphone pedestal in the helmet. Neither of these methods gave reliable respiration traces during flight, and a change was made to the impedance pneumograph for the last two missions. This device gave very accurate respiration information during most of the flight.

Electrocardiographic electrodes were of a low impedance to match the spacecraft amplifier. They were required to record during body movements and to stay effective during flight durations of over 30 hours. These electrodes functioned well and gave very good information on cardiac rate and rhythm. The value of having two leads of electrocardiograph, even though they differed from the standard clinical leads, was repeatedly shown. This allowed easier determination of artifacts and was most helpful in determining the valid sounds on the blood-pressure trace by comparison with the remaining ECG lead. The electrode paste was changed from 30-percent calcium chloride in water mixed with bentonite to a combination of carboxy polymethylene in Ringer's solution.

The ten times isotonic Ringer solution not only retained the necessary conductivity and low impedance required, but also afforded decreased skin irritation after prolonged contact.

In 1958, the obtaining of blood pressures in flight was considered and then delayed as no satisfactory system was available. Definitive work began about the time of the Mercury-Redstone 3 (MR–3) flight, and the automatic system which used the unidirectional microphone and cuff was developed for use in the orbital flights. This system without the automatic feature was used on the MA–6 mission of Astronaut Glenn. During the MA–7 mission, all of the inflight blood pressures obtained were elevated, and an extensive postflight evaluation program was undertaken. It was determined that the cause of these elevations was most likely instrumentation error resulting from the necessity for very careful gain settings matched to the individual astronaut along with the cuff and microphone. A great deal of preflight calibration and matching of these settings was done prior to the MA–8 flight; and on both MA–8 and the last mission, MA–9, very excellent blood-pressure tracings were obtained.

Voice transmissions have been a very valuable source of monitoring information. The normal flight reports and answers to queries have been used for evaluation of the pilot. In order to insure that the monitors were familiar with the astronaut's voice, tapes of mission simulations with the flight astronaut as a pilot were dispatched to all of the range stations for use in preflight simulations. In addition to normal reports, verification of actual comfort level was very valuable in determining the importance of temperature readings obtained by way of telemetry. Inflight photography and, on the last mission, television views of the astronaut have been planned as additional data sources. In Mercury experience, both of these sources have proven to be of very little value in the medical monitoring of the astronaut because of poor positioning of cameras and varying lighting conditions resulting from the operational situation. A full face view of the astronaut in color on a real-time basis would be a good monitoring tool for it would approximate the clinical face-to-face confrontation of the patient.

The value of the comparison of multiple physiological parameters and their correlation with environmental data has been repeatedly proven. Abnormal or lost values attributed to instrumentation difficulty have frequently been obtained, but it has been found that interpretation of the astronaut's physiological condition could be made by the use of the parameters remaining or the correlation of those remaining with environmental data.

It has been interesting to note that a satisfactory amount of information on current astronaut status can be obtained with the use of such basic vital signs or viability measures. It is realized that the monitoring methods may be far from ideal. They did not provide the ultimate in the measure of man's physiological status. It would have been desirable to have a single parameter which would tell the ground monitor whether the nervous system of the pilot was capable of the peak mission performance necessary. To date, however, there is no such single or even multiple measures; and an attack must be made upon this problem from the periphery. It is believed that at present the raw physiological data cannot be replaced by computer evaluation. The basic idea of computer reduction has merit, and help is certainly needed in relieving ground medical monitors of long periods of observation. At present, however, there appears to be no useful system to meet this demand.

In the postflight report on the MR–3 mission (ref. 3), it was stated that "the remote monitoring on a noninterference basis of parameters such as temperature, respiration, the electrocardiogram, and blood pressure in active men fully engaged in prolonged and exacting tasks, is a new field. Hitherto, flight medicine has accepted the information concerning the well-being that could be derived from the pilot's introspection and conveyed by the invaluable voice link. For the rest it has relied on performance to tell how close the man was to collapse. It is to be hoped that some of the developments in automation necessitated by Project Mercury will find application in clinical medicine."

This hope is rapidly coming to fruition in the light of the wide activities in medical monitoring now being carried on in everyday medicine.

## Physiological Responses to Space Flight

One of the basic objectives of the Mercury flights was the evaluation of man's physiological responses to exposure to this space-flight environment. These responses also had implications as to his performance capability in this environment. The stresses of this environment to which physiological responses are elicited include the wearing of the full-pressure suit although not pressurized in flight, confinement and restraint in the Mercury spacecraft with the legs at a 90° elevated position, the 100-percent oxygen 5-psi atmosphere, the changing cabin pressure through powered flight and reentry, variation in cabin and suit temperature, the acceleration force (g force) of launch and reentry, varying periods of weightless flight, vibration, dehydration, the performance required by the flight plan, the need for sleep and for alertness, changes in illumination inside the spacecraft, and diminished food intake.

Sources of data used in evaluating these responses have included the control baseline data previously referred to, data from the biomedical sensors received at both the Mercury Control Center and the range stations, voice responses at these stations and the detailed onboard tape, the film record of the onboard tape, answers to debriefing questions, and the detailed postflight examination.

In considering these physiological responses, it was found necessary to have a detailed inflight event history since the peak physiological responses are closely related to critical inflight events. This meaningful relationship is very well demonstrated in considering the pulse responses to the Mercury flights. The peak pulse rates during the launch phase has usually occurred at sustainer engine cut-off. This peak value has ranged from 96 to 162 beats per minute. The peak rates obtained on reentry have ranged from 104 to 184 beats per minute. This peak usually occurred immediately after obtaining peak reentry acceleration, or on drogue parachute deployment. Pulse rates obtained during weightless flight have varied from 50 to 60 beats per minute during the sleep periods to 80 to 100 beats per minute during the normal wakeful periods. (See table 11–I.) Elevated rates during weightless flight can usually be related to flight-plan activity. The respiratory

*Table 11–I.—Pulse Rates*

| Mission | SECO (Peak) | Weightlessness (Range) | Reentry (Peak) |
|---|---|---|---|
| MR–3 | 138 | 108 to 125 | 132 |
| MR–4 | 162 | 150 to 160 | 171 |
| MA–6 | 114 | 88 to 114 | 134 |
| MA–7 | 96 | 60 to 94 | 104 |
| MA–8 | 112 | 56 to 121 | 104 |
| MA–9 | 144 | 50 to 60 (sleep)<br>80 to 100 (awake) | 184 |

rates have ranged from 30 to 40 breaths per minute at sustainer engine cut-off, from 8 to 20 breaths per minute during weightless flight, and from 20 to 32 breaths per minute at reentry. Changes noted in the electrocardiograms have included alterations in the pacemaker activity with wandering pacemakers and aberrant rhythm including atrio-ventricular nodal beats and rhythm, premature atrial and ventricular contractions, sinus bradycardia, atrial rhythm, and atrio-ventricular contraction. All of these "abnormalities" are considered normal physiological responses when related to the dynamic situation in which they were encountered. Inflight blood-pressure values and body-temperature readings have all been within the physiologically normal range.

The six astronauts who have flown have shown themselves capable of normal physiological function and performance during the acceleration of launch and reentry. The launch accelerations are those imposed by the Redstone and the Atlas launch vehicles. These impose a peak transverse acceleration load of 11g in the case of the Redstone and 7g to 8g in the case of the Atlas.

The vibration produced by launch or reentry has been well tolerated in all cases.

There has been no conclusive evidence of disorientation during flight; and while the astronaut may not have been oriented with respect to the earth, he has always remained so with respect to his spacecraft. The lack of earth orientation has posed no problem whatsoever. There has been no evidence of motion sickness in any of the flight astronauts.

The heat loads imposed by the environmental control system have on occasion caused discomfort but have not been limiting factors in the

missions to date. The heat loads and decreased water intake have resulted in postflight dehydration. It has been learned that thermal control in the environmental system is of critical importance.

The Mercury missions were originally planned for altitudes which would not involve contact with the Van Allen Belt of radiation. It was therefore believed that radiation posed no problem in the conduct of these missions, and this was the case until the man-made radiation belt was noted just prior to the MA–8 mission. Personal dosimeters were added within the astronaut's suit and inside the spacecraft at this time in addition to the film packs which had originally been carried. The results obtained from this dosimetry on the last two flights revealed that the astronauts have received no more radiation dose than they would have received had they been here on earth and certainly less than that received during a chest X-ray.

The Mercury program has provided incremental exposures to weightless flight in order to obtain information on which to base predictions of reactions to more prolonged exposures. The crews have uniformly reported that the condition is extremely pleasant and restful. In fact, most of the crews think that it is the only time they have been comfortable in a pressure suit. They have conducted complex visual motor coordination tasks proficiently in the weightless environment. No evidence of body system disfunction has been noted during the period of weightless flight through any of the means of monitoring at our disposal. Food, in cube, liquid, and reconstituted freeze-dried forms, has been eaten normally. Urination has occurred quite normally in timing and amount, and there is no evidence of difficulty in intestinal absorption in the weightless state. Our one experience with sleep periods has raised the question as to whether brief periods of sleep in the weightless condition are more restful than the same periods in a lg atmosphere. The MA–9 astronaut feels that they are. There is also some question concerning the effect of such a relaxing condition as weightlessness because a number of unscheduled naps occurred. This question will require further investigation on other flights. In the missions to date, there has been no evidence of the mobilization of calcium.

On the last two missions, some postflight orthostatic hypotension, or changes in blood pressure and pulse rate with change in body position, has been noted. This postflight condition has been investigated by the use of the tilt table during the last mission and these results confirm what was only a suspicion on the previous mission. Symptoms of faintness occurred following egress from the spacecraft, and the changes in blood pressure and pulse rate were present for some 7 to 19 hours after landing. In both instances, these changes have been present up until the astronaut retired for the night, a time period of approximately 7 hours; and they have always disappeared by the time of the first check after the astronaut has awaken. Thus, the orthostatic changes have lasted no longer following the more prolonged flight in the MA–9 mission than for the shorter flight; and in both instances, blood pressure and pulse rate have returned to normal while the astronaut was at bed rest. These findings do cause concern about prolonged exposure without some interim steps for further evaluation of this condition.

### Recovery

The medical support of the overall Project Mercury recovery operation had to meet two basic requirements:

(1) The capability of providing prompt, optimum medical care for the astronaut, if necessary, upon his retrieval from the spacecraft.

(2) The provision for early medical evaluation to be made of the astronaut's postflight condition.

It was considered essential to establish a medical capability for any circumstance under which recovery could occur. The general concept was to provide the best care in the fastest manner possible. Details of the medical recovery requirements may be found in the appropriate NASA documents (refs. 1, 4, 7, 10, and 12). The original plans were necessarily based on anticipating the direst situation expected, and very correctly so. The extent of medical care which could be effectively administered to the astronaut during the recovery operation is governed to a large degree by the physical circumstances under which recovery occurs. Consequently, the level of medical support necessary at the different recovery areas varies

according to the potential extent to which competent medical treatment can be administered in that area, and the most extensive medical support is properly concentrated in those areas where descent to earth by the astronaut is most probable. Access times for the various recovery areas were determined to be medically acceptable time periods to allow reasonable protection of the astronaut based upon accumulated knowledge of human survival, need for medical attention, and reaction to physiologic stress. Since the recovery forces are routine operational units diverted to this operation by the Department of Defense, it also became obvious that the medical support must be obtained through the cooperation of the Department of Defense. Civilian physicians are not available for deployment for the necessary time periods. It will be noted that one of the basic philosophy changes during the program involved a change in emphasis from taking medical care to the astronaut in the early missions to provisions for returning the astronaut to definitive medical care in the later missions. The medical support was provided for three basic categories:

(1) Rapid crew egress and launch-complex rescue capability during the late countdown and early phases of powered flight.

(2) Positive short-time recovery capability throughout all phases of powered flight and landing at the end of each orbital pass.

(3) Reduced capability in support of an unplanned landing along the orbital track.

In the launch-site area, this support included a medical-specialty team consisting of a general surgeon, an anesthesiologist, surgical technicians and nurses, a thoracic surgeon, an orthopedic surgeon, a neurosurgeon, an internist, a radiologist, a pathologist, a urologist, a plastic surgeon, and supporting technicians. In the early missions, these individuals were deployed to Cape Canaveral and were available should the need arise for their use either at Cape Canaveral or, in the event of a requirement for their services in the recovery area, they could be dispatched by aircraft. On the last two missions, it became necessary to develop a team at Tripler Army Hospital, Hawaii, to cover the Pacific area as well as a team deployed to Cape Canaveral to cover the Atlantic area. It became obvious that there were large numbers of highly trained physicians who were merely waiting out the mission in a deployed state with an unlikely probability that they would be utilized. Careful evaluation of the experience and of sound medical principles involving emergency medical care led to the conclusion that the specialty team could be maintained on standby at a stateside hospital and easily flown either to Cape Canaveral or a recovery site if their services were needed. There were surgical resuscitatives teams available at these sites. Other launch-site support was provided by a point team consisting of a flight surgeon and scuba-equipped pararescue personnel airborne in a helicopter. Medical technicians capable of rendering first-aid care were also available in LARC vehicles and in a small water jet boat stationed on the Banana River. A surgeon and an anesthesiologist with their supporting personnel were stationed in a blockhouse at Cape Canaveral to serve as the first echelon of resuscitative medical care in the event of an emergency. Physicians were stationed throughout the recovery areas aboard destroyers and aboard one aircraft carrier in the Atlantic and one in the Pacific. In the early missions each vessel was assigned a surgeon, anesthesiologist, and a medical technician team with the supporting medical equipment chest necessary for evaluation and medical or surgical care. As confidence was gained in the operations, this distribution was modified to assigning only a single physician, either surgeon or anesthesiologist, to the destroyer. Attempts were made to place a surgeon on one and an anesthesiologist on another vessel nearby. This would allow their teaming up if necessary. The general concept was, however, that they would provide resuscitative care only and then evacuate the astronaut to the carrier in their particular area. The carrier was provided a full surgeon, anesthesiologist, technician team. Hospitals along the orbital track were alerted for their possible use, and some near planned landing areas were briefed by NASA-DOD teams. These briefing are thought to be extremely valuable aids in assuring adequate medical support. Early in the missions, blood was drawn from donors and made available for transfusion at Cape Canaveral and in the recovery area. As the operation grew wider in scope involving the Pacific, and as more confidence was gained, dependence was

placed upon walking blood bank donors who were typed, and drawn blood was available only in the launch site area.

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## References

1. Jackson, Carmault B., Jr., Douglas, William K., et al.: *Results of Preflght and Postflight Medical Examinations.* Proc. Conf. on Results of the First U.S. Manned Suborbital Space Flight. NASA, Nat. Inst. Health, and Nat. Acad. Sci., June 6, 1961, pp. 31–36.
2. Augerson, William S., and Laughlin, C. Patrick: *Physiological Responses of the Astronaut in the MR–3 Flight.* Proc. Conf. on Results of the First U.S. Manned Suborbital Space Flight. NASA, Nat. Inst. Health, and Nat. Acad. Sci., June 6, 1961, pp. 45–50.
3. Henry, James P., and Wheelwright, Charles D.: *Bioinstrumentation in MR–3 Flight.* Proc. Conf. on Results of the First U.S. Manned Suborbital Space Flight. NASA, Nat. Inst. Health, and Nat. Acad. Sci., June 6, 1961, pp. 37–43.
4. Douglas, William K., Jackson, Carmault B., Jr., et al.: *Results of the MR–4 Preflight and Postflight Medical Examination Conducted on Astronaut Virgil I. Grissom.* Results of the Second U.S. Manned Suborbital Space Flight, July 21, 1961. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 9–14.
5. Laughlin, C. Patrick, and Augerson, William S.: *Physiological Responses of the Astronaut in the MR–4 Space Flight.* Results of the Second U.S. Manned Suborbital Space Flight, July 21, 1961. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 15–21.
6. Douglas, William K.: *Flight Surgeon's Report for Mercury-Redstone Missions 3 and 4.* Results of the Second U.S. Manned Suborbital Space Flight, July 21, 1961. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 23–31.
7. Minners, Howard A., Douglas, William K., et al.: *Aeromedical Preparation and Results of Postflight Medical Examination.* Results of the First United States Manned Orbital Space Flight, February 20, 1962. Supt. Doc., U.S. Government Printing Office (Washington, D.C.) pp. 83–92.
8. Laughlin, C. Patrick, McCutcheon, Ernest P., et al.: *Physiological Responses of the Astronaut.* Results of the First United States Manned Orbital Space Flight, February 20, 1962. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 93–103.
9. Johnson, Richard S., Samonski, Frank A., Jr., Lippitt, Maxwell W., and Radnofsky, Matthew I.: *Life Support Systems and Biomedical Instrumentation.* Results of the First United States Manned Orbital Space Flight, February 20, 1962. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 31–44.
10. Minners, Howard A., White, Stanley C., et al.: *Clinical Medical Observations.* Results of the Second United States Manned Orbital Space Flight, May 24, 1962. NASA SP–6, Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 43–53.
11. McCutcheon, Ernest P., Berry, Charles A., et al.: *Physiological Responses of the Astronaut.* Results of the Second United States Manned Orbital Space Flight, May 24, 1962. NASA SP–6, Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 54–62.
12. Berry, Charles A., Minners, Howard A., McCutcheon, Ernest P., and Pollard, Richard A.: *Aeromedical Analysis.* Results of the Third United States Manned Orbital Space Flight, October 3, 1962. NASA SP–12, Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 23–36.

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# III

# FLIGHT OPERATIONS

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# 12. SPECIAL INFLIGHT EXPERIMENTS

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## Summary

The Mercury spacecraft, although not designed as a vehicle for performing experiments, was used to accomplish a program of special inflight experiments not directly related to mission objectives. The major constraints imposed on the experiment program by the spacecraft were the weight and volume requirements, and the consumables required such as attitude-control system fuel and electrical power. The program evolved from an early period when no planned experimental endeavor existed through the development and implementation of an inflight experiments panel specifically chartered to evaluate the growing number of proposed inflight experiments. The inflight experimental program carried out during the Mercury manned orbital flights is outlined in this paper and the results of these experiments are briefly presented. An analysis of the results of those experiments performed in the area of the physical sciences is presented in paper 19.

## Introduction

A major objective of the Mercury manned space-flight program was the determination of man's ability to function in the space environment. The Mercury spacecraft was designed to sustain a man in space for a given period of time and to protect him against the accelerations and temperatures to be encountered during exit from and reentry into the earth's atmosphere. Because of the emphasis on the sustentation and protection of man in space in the design stages, practically no consideration was given to the employment of the spacecraft as a platform for specific inflight experiments. Astronaut safety was the prime design consideration; and, even in the latter stages of the Mercury Project, this concept was not compromised by the desire to perform experiments.

However, an inflight experiment program was evolved in the latter stages of the Mercury Project within the constraints imposed by the spacecraft and operational requirements. The experiments, in general, fall into three categories—biomedical, physical sciences, and engineering. The biomedical experiment program is described in paper 11 and is not covered herein.

This paper discusses the constraints placed on the Mercury experiment program by the spacecraft and the operational limitations, describes the procedures which evolved for the evaluation and implementation of experiments, and summarizes the Mercury inflight experiment program. An analysis of those experiments in the area of space sciences is made in paper 19.

## Spacecraft Constraints

### Weight

The maximum allowable weight of the Mercury spacecraft was dictated by the capability of the Atlas launch vehicle and by the requirement to achieve an extremely high probability of satisfactory orbital insertion. The entire 5-year history of the Mercury Project has been marked by a constant struggle to maintain the weight of the spacecraft within the weight constraints. Even without the addition of inflight experiments, the spacecraft weight was still increasing approximately 1 pound per week at the close of the program.

After the first manned orbital mission, when it was shown that man can function reliably in the space environment and is a competent technical observer, an increasing amount of spacecraft weight was devoted to the accom-

plishment of experiments. The battle to reduce the weight of the Mercury spacecraft had not been won by any means; but weight devoted to the performance of experiments was considered to be justified by the fact that Mercury became a part of a growing national program of scientific space exploration for peaceful purposes.

The weight associated with experimental equipment carried on each of the Mercury manned orbital missions is tabulated as follows:

| Mission | Weight, lb |
|---|---|
| MA–6 | 11 |
| MA–7 | 18 |
| MA–8 | 22 |
| MA–9 | 62 |

### Volume

An observation of the Mercury spacecraft interior, particularly with the astronaut in place and wearing his pressure suit, impresses one with the compactness of the spacecraft and the lack of available volume. Several worthy suggestions for experiments were rejected simply because there was no space available to store the equipment required for the experiment. A relatively small hand-held camera, for example, became a major problem because of no suitable place to stow it for launch and reentry. Although the astronauts have had available to them a personal-effects container, this storage space was rapidly filled with food, flight plans, star charts, and other paraphernalia required for the flight. Astronaut Cooper on the MA–9 mission managed to squeeze into this bag two cameras together with associated film magazines and lenses, but he experienced a great deal of difficulty in extracting and storing his camera equipment. One planned experiment could not be completed because a piece of equipment could not be taken from the container.

### Operational Limitations

On the two, three–orbital–pass missions, the short duration of these flights allowed little time for experimental observations. In general, on such a mission, the astronaut used the first orbital pass to acclimate himself to the space environment and verify proper systems operation. The major portion of the third orbital pass was devoted to preparations for retrofire and reentry. Thus, only part of a continuous 90-minute period was available for the performance of experiments. On both the manned three–pass missions, control–system difficulties forced the astronauts to devote their attention to flying the spacecraft. Although the time available was limited, both Astronauts Glenn and Carpenter were able to make observations of scientific interest. Even on the 34–hour manned 1–day mission (MA–9), the requirements for engineering and operational data, astronaut rest periods, communications, and other duties resulted in only a limited time available for experiments.

A major constraint on the selection of experiments for the Mercury spacecraft was the small amount of control-system fuel available for experiments. At least some degree of attitude control of the spacecraft was required for practically all of the experiments. After reserves were first established for operational requirements, in particular the retrofire and reentry maneuvers, the fuel available for experiments was allocated according to priorities established for the experiments.

Other limitations imposed by the spacecraft consumables were requirements for electrical power and for data–recording channels. While these limitations were not severe, they were additional considerations in the selection of experiments.

Some types of experiments require an extremely accurate control of spacecraft attitude. Such fine control was not designed into the Mercury spacecraft because of weight limitations and the necessity for conserving control-system fuel. The automatic-control system, for example, had a deadband of up to 11°. The manual-control system and the attitude and rate indications to the astronaut were such that the astronaut could control the spacecraft attitude within a deadband of approximately only 2°. These tolerances made the spacecraft unsuitable for certain types of experiments.

The optical qualities of the Mercury spacecraft window were limited to begin with, and even these qualities were considerably degraded by residue from the escape rocket which was normally ignited when the escape tower was jettisoned just after launch-vehicle staging. Fu-

ture spacecraft will require some type of high-quality optical port if precision photographic experiments are to be conducted.

### Evalution and Selection of Experiments

Prior to the MA–6 manned orbital flight, no formal procedures existed for the acceptance, evaluation, and incorporation of proposed experiments in the Mercury missions. Suggestions were made informally by organizations both within and outside of the Manned Spacecraft Center for certain types of observations or photography to be accomplished on the MA–6 mission. These suggestions were made directly to the office responsible for astronaut training activities; and, where possible, certain of the suggested experiments were incorporated into the MA–6 flight plan.

With the successful accomplishment of the MA–6 mission, the original objective of the Mercury Project was fulfilled. It had been proven that man could function effectively in space and be safely recovered. With the realization that the Mercury Project was now in a position to perform certain types of experiments of scientific value from an orbiting spacecraft, the Mercury Project Office became the recipient of a large number of proposals for such experiments. These proposals originated from divisions within the Manned Spacecraft Center, other organizations and centers within the NASA, industry, and educational institutions. It was soon evident that a special organization was needed to serve as the focal point of the effort devoted to inflight experiments.

In April 1962, the Manned Spacecraft Center officially established the Mercury Scientific Experiment Panel (MSEP). This panel was made up of representatives of the Mercury Project Office and all technical, operational, aeromedical, and scientifically oriented divisions of MSC. The MSEP was specifically charged with the following responsibilities:

(1) To evaluate inflight experiments proposed for inclusion in Project Mercury missions.

(2) To propose to the manager of the Mercury Project the order of priority in which acceptable experiments should be incorporated into the program.

(3) To seek out and foster the generation of suitable experiments from all available sources.

In carrying out these responsibilities, the MSEP formed a close working relationship with scientists in the NASA Office of Space Sciences and the NASA Goddard Space Flight Center.

The major considerations in the evaluation of proposals for experiments by the MSEP were: scientific, technical, and biomedical merit; weight of equipment; volume and location of equipment; attitude-control-system fuel required; electrical power requirement; instrumentation requirement; effect on safety of flight; state of readiness and qualification of equipment and effect on spacecraft schedule; and extent of changes required to the spacecraft.

The MSEP functioned effectively for the MA–7 and MA–8 missions. With the approach of the MA–9 manned one-day mission, however, it became increasingly evident that the scope of the MSEP should be enlarged to include consideration of scientific experiments for MSC's advanced programs and to encompass a broader background of scientific interest.

To accomplish this broadening of responsibilities, the MSEP was supplanted in October 1962 by the Manned Spacecraft Center In-Flight Experiments Panel (IFEP). The IFEP difers from the MSEP in that its membership was enlarged to include representatives of the other two spacecraft project offices and an ex–officio member from the NASA Office of Space Sciences. Its recommendations for the implementation of experiments are made to the Director of the Manned Spacecraft Center for approval. The chairman of the IFEP is the MSC Assistant Director for Engineering and Development.

It is the policy of the MSC to make maximum use, for scientific and research purposes, of the flights scheduled under approved spacecraft programs. In keeping with this policy, the Center encourages the development of worthwhile investigations which can be implemented on manned flights within the limitations of operational requirements and flight safety. To promote this policy, the IFEP has established formal procedures for the submission, evaluation, and acceptance of proposals for inflight experiments.

### Implementation of Experiments

The IFEP recommends to the MSC Office of the Director the experiments for a given spacecraft mission. With the approval of the Director, these experiments become the official experiments for the mission. An experiment coordinator was appointed from within MSC for each of the approved experiments. His responsibility was the timely development and flight qualification of hardware required for the experiment. In general, the equipment required for an experiment was furnished by the organization which had proposed the experiment.

The Mercury Project Office was responsible for the integration of experimental equipment into the Mercury spacecraft. The experiment coordinator submitted the following documentation for an approved experiment:

(1) A firm schedule showing all significant milestones for the delivery of equipment

(2) A qualification plan in accordance with specified requirements

(3) A weekly status report

To prevent the spacecraft schedule from being affected by the integration of experiments, it was necessary to set the delivery date of experimental equipment well in advance of the scheduled launch date. In a normal prelaunch schedule for a Mercury spacecraft, the final checkouts of the spacecraft and its systems are made 8 weeks prior to the scheduled launch date. Once these tests were complete, absolutely no changes were made to the spacecraft except those dictated by flight-safety considerations. Therefore, the experimental equipment was required to be at the launch site 3 months prior to the scheduled launch in order to allow sufficient time for the installation and checkout of this equipment before the final spacecraft tests were begun. It was also imperative that the flight astronaut be thoroughly familiar with the equipment and trained in its use. It becomes apparent, then, that the selection and evaluation procedure for experiments must be completed many months before the scheduled launch of a spacecraft to allow time for the design, construction, and qualification of equipment before the required delivery date.

It was specified that the qualification environments and the levels of these qualification tests for experimental equipment be no less stringent than the qualification testing that was required of all Mercury spacecraft systems. The possibility of the compromise of a Mercury mission because of the failure of a piece of experimental apparatus could not be tolerated. Failure modes of the experimental apparatus were examined very closely to assure that such failures could have no degrading effect on the mission or on pilot safety.

The responsibility for integrating experiments into the mission flight plan and into the astronaut training activities was that of the MSC Flight Crew Operations Division. This division worked closely with other elements of MSC to develop a flight plan for each mission which would accomplish the mission objectives and would, at the same time, provide for the performance of experiments. It was necessary that the flight plan be completed in final form many weeks prior to a mission so that the training of the flight astronauts in the procedure trainers would conform with the flight plan. Once the final phases of astronaut training in preparation for the mission had begun, the flight plan could not be changed except for compelling reasons because late changes could seriously disrupt the astronauts' training status to the point where mission safety could have been affected. This, then, was the second reason why experiments must have been approved for a given mission many months in advance.

### Mercury Inflight Experiment Program

With this brief background on how the experimental program in manned space flight has evolved, a review of the results of the Mercury experimental program will now be presented. These experiments generally can be divided into two major categories. The first category, that of special inflight experiments, is the topic of this paper. The second category, that of analysis of observations and comments on the space environment and astronomical phenomena, is discussed in paper 19.

### Planned Inflight Experiments

The inflight experiments planned for and carried out during the Mercury Project can be grouped generally into several areas of study. These areas are: (1) visual acquisition and perception experiments, (2) general photo-

graphic experiments, (3) radiation experiments, (4) tethered balloon experiment, and (5) several miscellaneous studies which include investigations of fluid behavior under zero gravity and of the characteristics of various ablative materials under reentry conditions.

### Visual Acquisition and Perception Studies

In future space flights it may be necessary for astronauts to acquire and track lighted targets either on the ground or in space to provide a backup capability for rendezvous and navigation. Visual acquisition of a target in space may also be used to back up the primary method of rendezvous with other space vehicles. Experiments were, therefore, undertaken on Mercury flights to evaluate the operational problems associated with visual acquisition from space of both earth-based lights and lighted targets ejected from the spacecraft.

*Ground-light experiments.*—Attempts were made on each of the manned orbital Mercury flights to sight known earth-based lights at night. These studies were expected to provide information on man's ability to acquire a fixed light source against an earth background and determine to what extent targets of this type would prove useful as navigational aids in space. An attempt was made by Astronaut Glenn to sight flares launched by mortars from the Indian Ocean Ship on the first and second orbital passes of the Mercury–Atlas 6 (MA–6) flight. The astronaut was unsuccessful in his attempts to see these flares, however, because of heavy cloud coverage in the area. Attempts were again made to acquire ground flares of 1,000,000 candle-power intensity over the Woomera missile range in Australia on both the Mercury–Atlas 7 (MA–7) and Mercury–Atlas 8 (MA–8) missions. These experiments were also unsuccessful on both flights because heavy cloud cover and poor visibility prevented the pilots from sighting these targets. A ground-based xenon light located at Durban, South Africa, was also used on the MA–8 mission to increase the probability of having favorable weather at one site. Unfortunately, rain and clouds obscured the light in South Africa as well as the ground flares in Australia. Another attempt to sight the xenon light was planned for the Mercury–Atlas 9 (MA–9) mission. By using statistics furnished by the U.S. Weather Bureau to determine a favorable location, the light was positioned at Bloemfontein, South Africa. Sightings were scheduled for the sixth orbital pass and in this case Astronaut Cooper was successful in acquiring the light.

The light assembly used for this experiment, shown in figure 12–1, was a pulsed xenon arc light consisting of three sections of six lamps each. The lamps were mounted in a shallow open–top box above a polished reflector and were operated by using a 50–cycle, 220–volt, three–phase a–c circuit. Each section operated independently from a single phase and flashed once every cycle. Thus, the three sections produced a total of 150 flashes per second, well above the response of the eye, and appeared as a steady burning light. The measured average intensity of the light was found to be between 30,000 and 35,000 candle power and required between 13 and 15 kilowatts of power for operation. The light could first be viewed at a slant range of 320 nautical miles from the spacecraft and was calculated to be as bright as a 3.5 magnitude star. Astronaut Cooper estimated the light to be third magnitude in brightness when first acquired, and he was able to retain it in sight for 30 to 40 seconds before it faded out. Thus, the experiment produced sighting results approximately as predicted and the light was considered of sufficient brightness to be used as a navigational landmark. A flashing light or some distinctive light pattern, however, was believed essential for identification of a target light for any future use. The rapid angular passage of the spacecraft over the ground will also pose a problem for use of

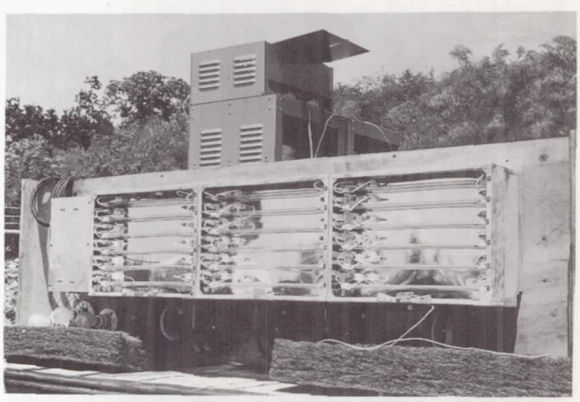


FIGURE 12–1.—Ground-light installation.



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ground targets of this sort as navigational fixes. Weather conditions on the ground also proved to be an important factor in using ground lights, and perhaps airborne lights carried above the weather region of the atmosphere would prove more dependable. More testing is needed to prove the operational feasibility of using airborne lights and to determine flash frequencies most desirable for acquisition and tracking.

*Flashing-light experiment.*—The problem of visual acquisition of other space vehicles directly relates to the rendezvous of two spacecraft. For visual sighting of another vehicle at ranges up to 100 miles, the problems of visual acquisition and tracking need to be identified and studied. Therefore, a study to investigate some of the problems of visual acquisition of a target vehicle in the space environment was carried out on the Mercury-Atlas 9 (MA-9) flight.

On this flight a flashing light was ejected from the spacecraft and viewed by the astronaut at varying distances in orbit. The light, its container, and the ejection mechanism were built by the NASA Langley Research Center, and the details of this assembly are shown in figure 12–2. The flashing-light unit was a 5.75–inch-diameter spherical assembly weighing about 10 pounds and equipped with two xenon-gas-discharge lamps located at opposite poles. The two lamps flashed simultaneously at a rate of approximately one signal per second. The beacon was designed to appear about as conspicuous as a second magnitude star when viewed at a distance of 8 nautical miles. As shown in the figure, the sphere was ejected from the container at a speed of 10 ft/sec by means of

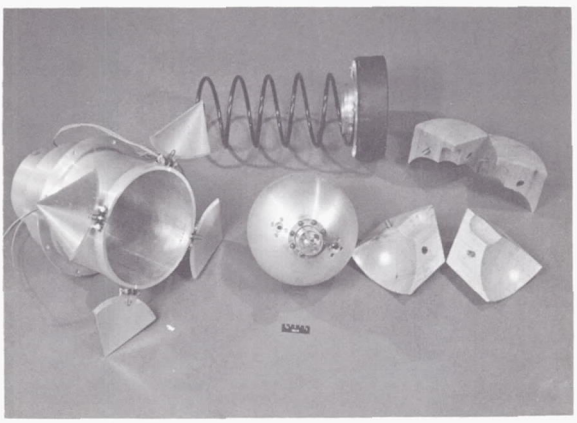


FIGURE 12–2.—Assembly for flashing-light beacon.

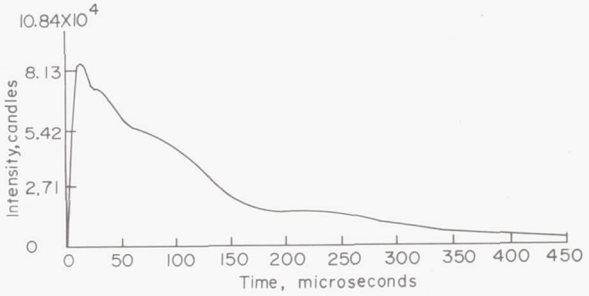



FIGURE 12–3.—Time history of a typical flash of the beacon.

a compressed spring acting against a piston when the canister covers were released. The light was powered by mercury-cell batteries, which were connected in series, and it delivered approximately 8 watt-seconds of power per flash.

A typical time history of one of the flashes is shown in figure 12–3. This figure shows that the light reached a peak intensity output of about $8.0 \times 10^4$ candles and that the light has a flash duration of about 100 microseconds at or above one-half peak intensity.

Extensive measurements were made by the National Bureau of Standards to determine the integrated light intensity and to establish that the distribution of the light was reasonably uniform in all directions and reasonably constant throughout its designed lifetime of 5 hours. Figure 12–4 is an example of this directional survey and shows the variation of integrated light output in candle-seconds per flash with light orientation. Distributional measurements of this type for varying viewing angles showed that the light output was reasonably uniform and produced a flash intensity of approximately 12 candle-seconds per flash. As shown by figure 12–4, regions near the 0° and 180° orientation showed some degradation in light intensity, with intensity falling as low as 8 to 9 candle-seconds in these regions. By using a value of 0.2 for the Blondel-Rey constant for threshold viewing of flashing lights, this light can be converted to an equivalent effective steady-light intensity of from 40 to 60 candles. This intensity corresponds to a light of second magnitude in brightness when viewed at a distance of between 7 and 8 nautical miles by using the commonly accepted value of 8.3 $\times 10^{-7}$ lumens per square meter for a first magnitude light. Visual air-to-air and ground-

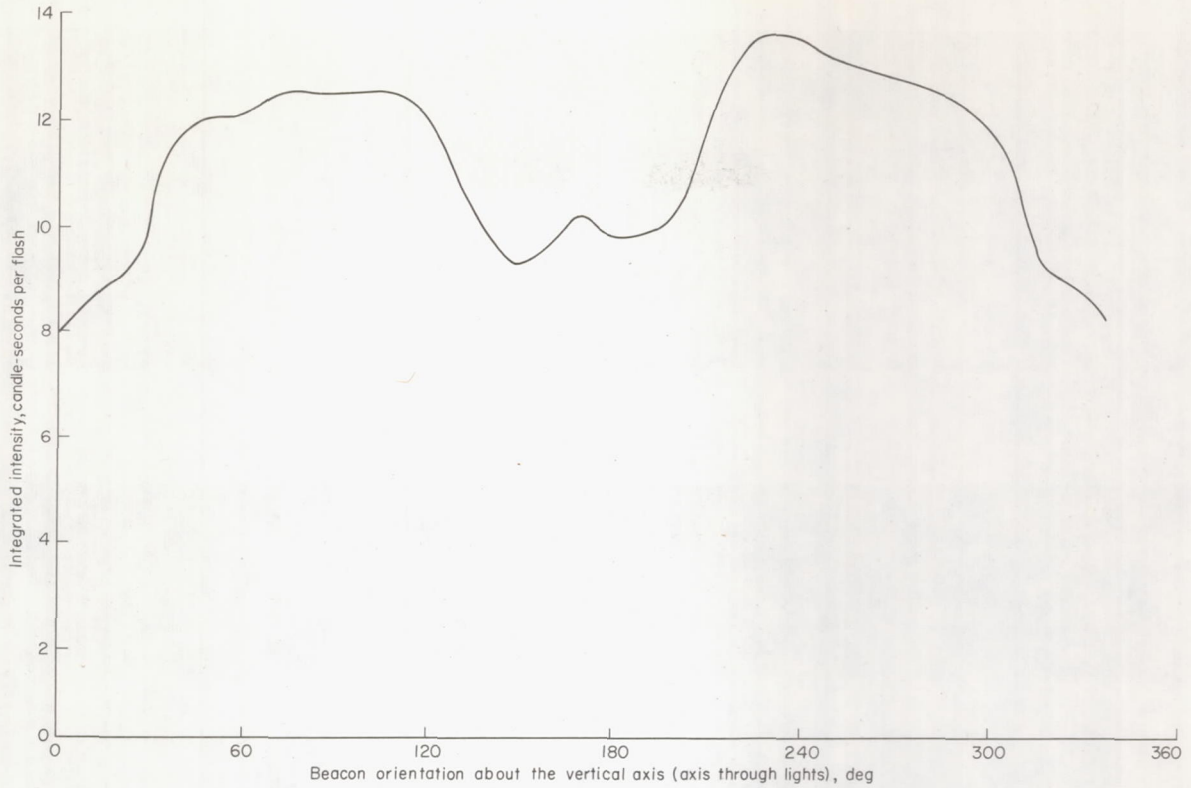



FIGURE 12–4.—Integrated intensity of the flashing beacon about an axis passing through the lights and inclined at 30° from the vertical.

sighting tests, with Astronaut Cooper as one of the test subjects, indicated that the light intensity was approximately the same as had been measured in the laboratory.

Trajectory studies of ballistic number, ejection angle, ejection velocity, and orbital position at ejection were made to determine the proper orbital conditions for deployment of the light. These studies showed that if the beacon were ejected 88° below the pitch horizon of the spacecraft at a velocity of 10 ft/sec, the desired trajectory would be obtained. Figure 12–5 shows the spacecraft attitude and canister location used to provide the desired ejection angle. The pilot controlled the spacecraft attitude to

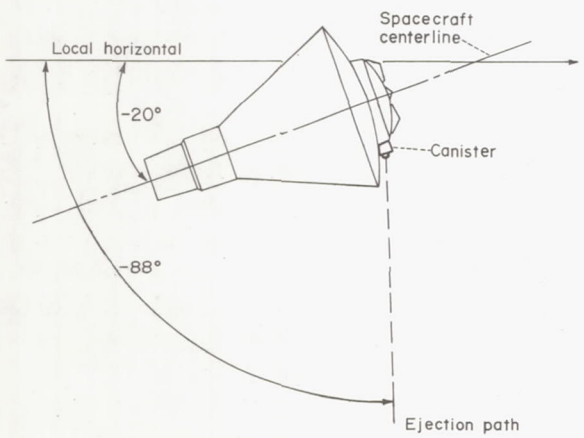



FIGURE 12–5.—Spacecraft orientation at beacon deployment.

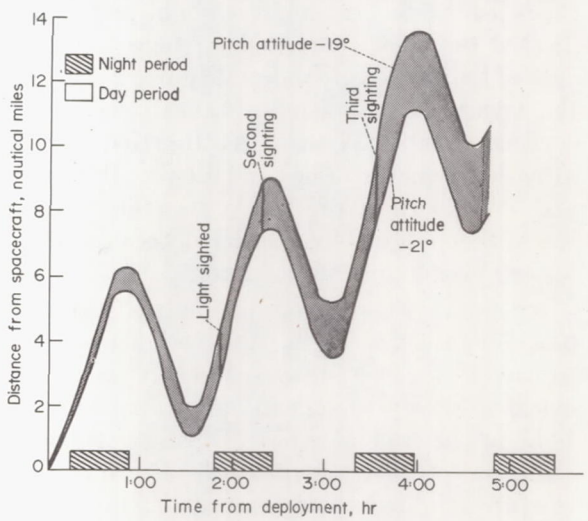



FIGURE 12–6.—Variation in separation distance between the spacecraft and the flashing beacon after deployment.

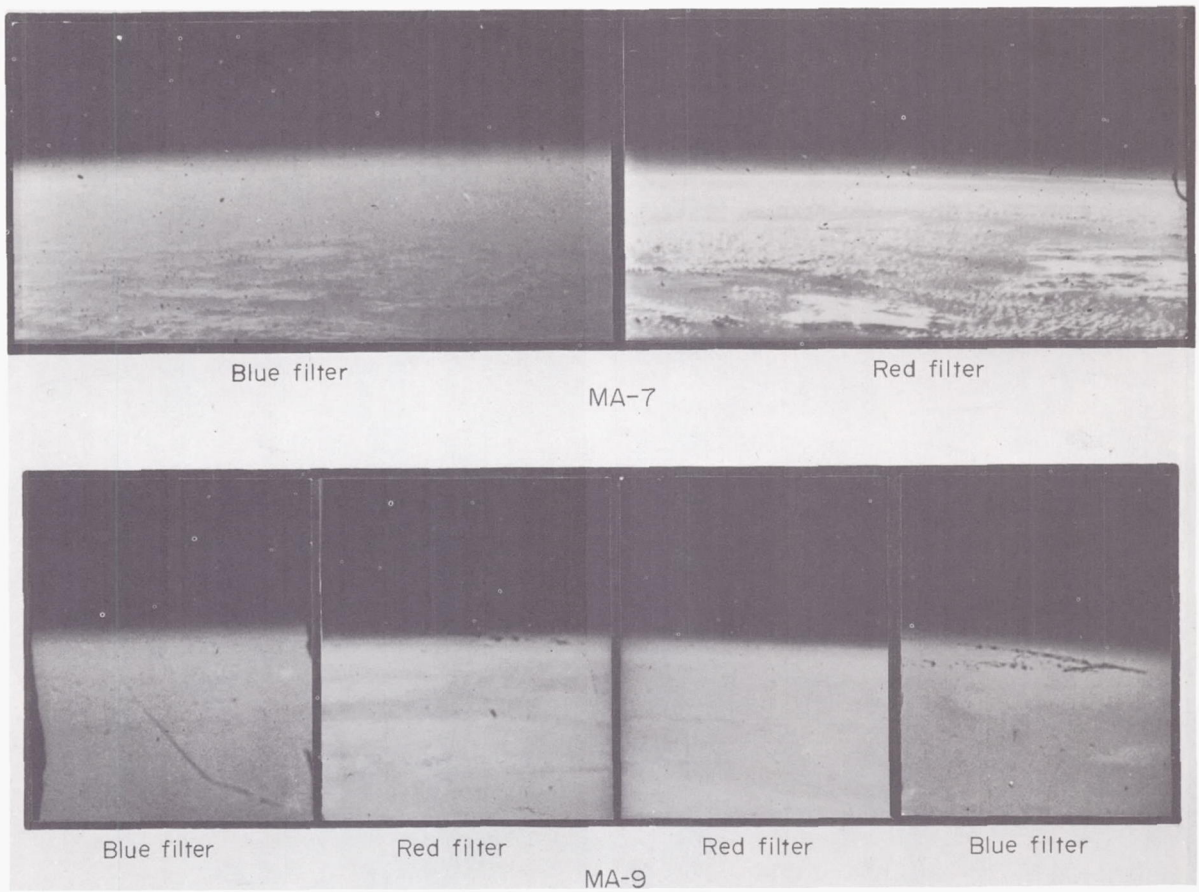



FIGURE 12–7.—Typical horizon definition photographs.

the desired position by using horizon-sighting markings on the window for aiming. The beacon was ejected 15 minutes prior to sunset on the third orbital pass and postflight records indicated the pilot controlled attitude to within $\pm 1°$ of the desired attitude. Figure 12–6 shows the calculated separation distance between the spacecraft and the beacon as a function of time after deployment. The band between the upper and lower curves represents the variation in range that might have occurred because of an uncertainty in ejection attitude.

Astronaut Cooper was unable to locate the beacon on the first night pass after deployment, probably because the spacecraft was not oriented closely enough in yaw to position the light in the field of view. During the second night pass after deployment the astronaut successfully sighted the beacon and was able to change the spacecraft attitude and then return to reacquire the light. During these sightings, noted on figure 12–6, the astronaut rated the light as about one star magnitude dimmer than had been expected. For example, when the beacon was between 7.5 and 9 nautical miles away at 2 hours and 14 minutes after deployment, the light was described as not very bright but discernible, about the order of a third magnitude star. The light was also seen during the third night at a range of between 9.5 and 11.5 nautical miles and was rated as very, very weak and just barely discernible.

In general, the flash was found to make the light easily distinguishable from stars. The beacon's intensity and flash rate appeared to be adequate for acquisition distances of up to 8 nautical miles at night which corresponded to a light intensity of about a second magnitude light.

### General Photography

*Horozin-definition photography.*—Horizon-definition photography was conducted on two Mercury space flights to assist the Instrumenta-

tion Laboratory of the Massachusetts Institute of Technology (MIT) in determining the effectiveness with which the earth's sunlit limb could be used for navigational sighting during the terminal phase of advanced space missions. Photographic studies were carried out on both the MA–7 and MA–9 flights. A 35–mm Robot camera was flown in MA–7 and a 70–mm Hasselblad was used as the photographic device for MA–9. For both flights, a special red and blue split filter was inserted in the field of view just ahead of the film plane. This filter was used to provide information on the resolution and effectiveness of using the limb as a navigation aid at the two extremes of the visible spectrum.

Data obtained from these photographic studies are presently being analyzed by Instrumentation Laboratory scientists under the direction of Dr. Max Peterson. Limited results of the MA–7 flight have shown, as expected, that the earth's limb viewed through a blue filter has a somewhat higher elevation than when viewed through a red filter. This distinction is clearly evident in figure 12–7 which shows typical photographs obtained on both the MA–7 and MA–9 flights. The MA–7 flight results have shown that contrast and definition are improved when viewed in the longer wavelengths of the visible spectrum (see fig. 12–7). The limb viewed through a blue filter is expected, however, to provide a better navigational reference because the blue limb appears more stable and is not as subject to interference effects from clouds and other atmospheric conditions as is the red limb.

The MA–9 photographic study was conducted to provide additional information on the limb elevation viewed through the red and blue filters. It was also planned to obtain information for determining the radiance of the limb, for evaluating the effect of variations in scattering angle of incident light on limb height, and to establish the height of the limb above the surface of the earth. To accomplish these objectives, it was planned to take a series of photographs in the four quadrantal directions relative to the sun, of the setting moon near the earth's limb, and of the limb during the daylight period of most of an orbital pass. It was not possible to obtain the daylight–period photographs on the MA–9 flight because of operational difficulties during the period in which this photography was planned.

A preliminary analysis of the MA–9 photographs taken substantiates the initial results of the MA–7 flight. Although the analysis is not yet complete, it is expected that the limb radiance in both the red and blue portions of the spectrum can be fairly accurately established. An accurate determination of the height of the limb cannot be made by using data from the MA–9 flight, however, because the image of the moon is too distorted and indistinct. The film and dust layer which collected on the spacecraft window might well have contributed to this indistinct image. Although no significant difference in limb height was noted when the four quadrantal photographs were compared, much more data covering a wide variation in the angle of incidence of sunlight striking the atmosphere are needed to determine the effect of variation in scattering angle on limb height. In order, therefore, to establish the value of the earth's limb as a navigational reference, additional studies are needed to determine limb height and the variation in this height at different scattering angles of incident light.

*Weather photography.*—Weather observations and photography were carried out during the Mercury flight program to augment other meteorological information and to provide specific information that would be useful in designing advanced weather satellite systems. On both the MA–6 and MA–7 missions, cameras equipped with special film and filters were carried on board for photographing interesting meteorological phenomena. However, because of difficulties arising during each of these flights, no photographs were obtained. Meteorological data obtained on these missions were derived from the astronauts' observations and the general-purpose color photography.

Photographic experiments were conducted during both the MA–8 and MA–9 flights for the National Weather Satellite Center. These experiments were designed to examine some of the spectral reflectance characteristics of cloud, land, and water areas of the earth's surface as viewed from space. Figure 12–8 shows the camera and filters used on these two flights. The 70–mm Hasselblad camera shown in the figure was used for both missions. For the

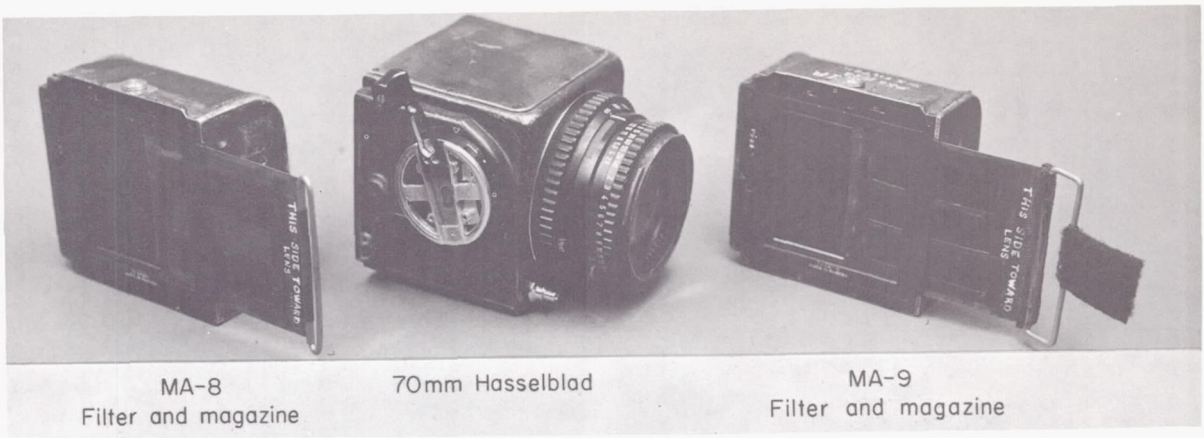



FIGURE 12–8.—Photographic equipment used for Weather Bureau experiment.

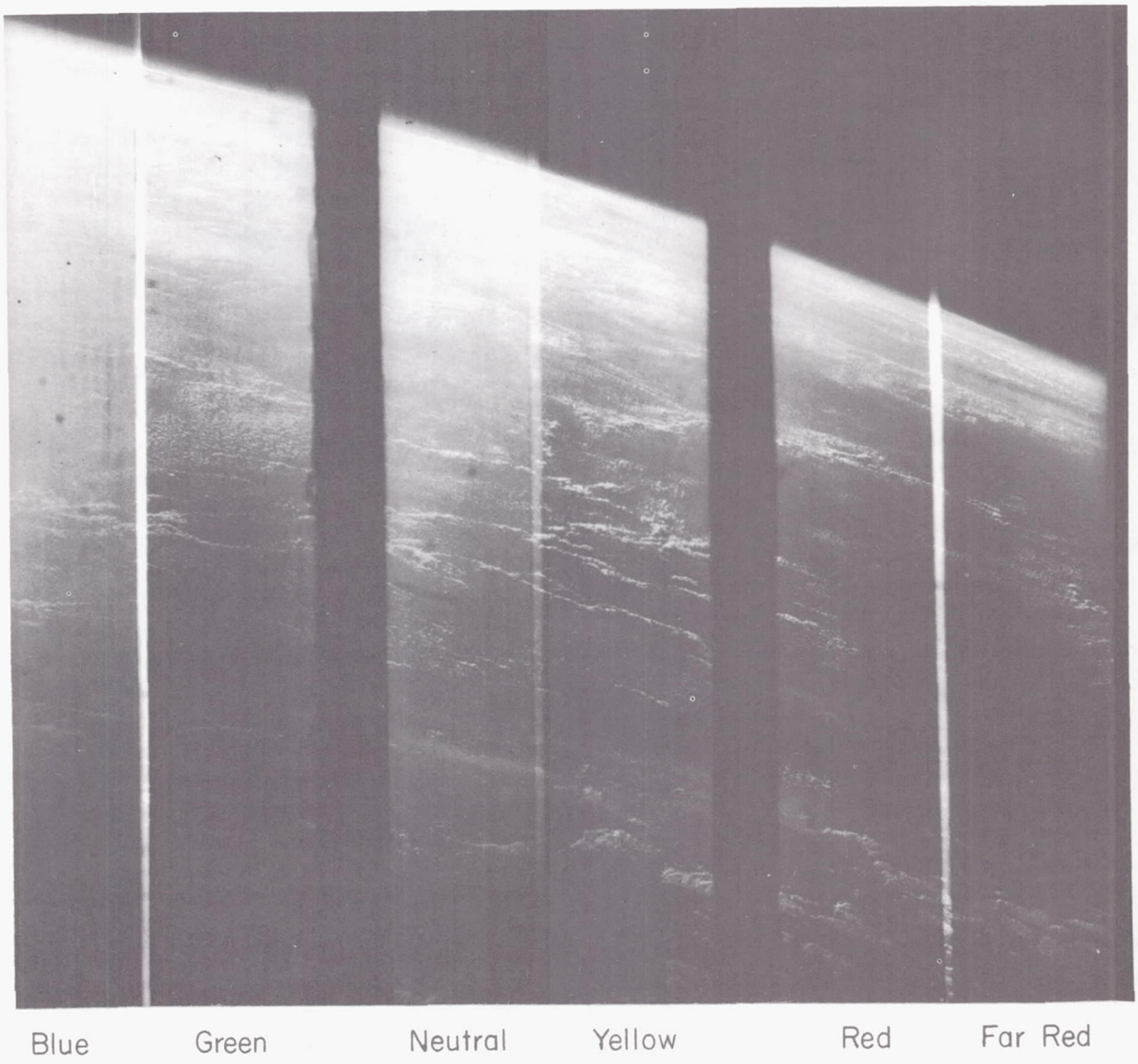



FIGURE 12–9.—Weather photograph of a region of the South Atlantic, southeast of Brazil taken by Astronaut Schirra on the MA–8 flight.




FIGURE 12–10.—Weather photograph of the Baja California area taken by Astronaut Cooper on MA–9.

MA–8 mission a wide bandpass Wratten filter consisting of six elements varied in range of spectral transmission from blue to far red. Neutral density was added to each of the color filters to produce a nearly uniform neutral density over the entire spectrum examined. Film sensitivity extended from 3,700 Å to 7,200 Å thus limiting the wavelength response to 7,200 Å.

Figure 12–9 is a photograph from the series obtained during the MA–8 flight and was taken over the South Atlantic on the fifth orbital pass. It was exposed at an altitude of 140 nautical miles viewing northwest toward the southeast coast of Brazil approximately 1,000 miles away. Analyses of this and other photographs of this series were carried out by Mr. Stanley Soules of the National Weather Satellite Center to provide design inputs to future weather satellites. Results from the MA–8 flight indicated that contrast increased with wavelength in the visible spectrum as shown by figure 12–9. These results indicate that the optimum wavelength for viewing the earth might be the near infra-red spectrum where scattering by atmospheric particles is relatively low.

The MA–9 weather photography was conducted to investigate this hypothesis by using infra-red film and a special filter shown in figure 12–10. This filter divided the infra-red spectrum from 6,600 Å to 9,000 Å into three parts. To accomplish this division of the spectrum, the filter was divided into three sections each having the bandpass width shown in figure 12–10, which is a typical photograph and was taken over southern Arizona looking westward. As pointed out by Mr. Soules in his analysis of these results, water has a very low reflectance in the near infra-red as shown by the dark portion on the left of the photograph covering the Pacific Ocean. Clouds and land have a very high reflectance; hence, coastlines and cloud patterns over water are easily discernible. However, as illustrated by the figure, clouds are more difficult to detect over land area because both the clouds and land areas covered with green vegetation have a high reflectance.

*Terrain photographs.*—Terrain photographs have constituted a portion of the general purpose photographs on each of the four manned orbital flights. However, they were specifically scheduled as a part of the flight plan on only the MA–8 mission. On the other three flights, terrestrial photographs were taken when the opportunity arose rather than as specifically planned activities. These photographs were taken to aid in building up a catalog of space photographs of various geological features such as folded mountains, fault zones, and volcanic fields, and to provide topographical information over a major portion of the earth's surface. They were taken on each flight by using high-speed color film in the general-purpose camera carried aboard for the flight. The following table lists the camera and exposure settings used on each flight.

Generally, the terrain photographs of the first three manned orbital flights were of poorer

| Flight | Camera | Film | Exposure |
|---|---|---|---|
| MA–6 | 35–mm Ansco Autoset | Eastman color negative stock no. 5250 | Automatic |
| MA–7 | 35–mm Robot Recorder | Eastman color negative stock no. 5250 | 1/125 at f/16 |
| MA–8 | 70–mm Hasselblad | Super Anscochrome color ASA no. 160 | 1/125 at f/11 |
| MA–9 | 70–mm Hasselblad | Ultraspeed Anscochrome color FPC 289 | 1/250 at f/16 |

quality than those obtained on the MA–9 mission, although some useful photographs were obtained on each of these flights. The reduced quality of the photographs on these first missions resulted primarily from the much poorer weather conditions that existed over the land areas of the earth and by the limited land area covered during the flights. It was quite fortunate that worldwide weather conditions during the MA–9 mission were much better than on previous flights; and because of the favorable weather and the fact that the flight covered many land areas of the world, excellent photographic coverage, particularly regions of the African and Asian deserts and the Himalaya mountains, was possible.

Preliminary analysis of these photographs has been made by Mr. Paul D. Lowman of the NASA Goddard Space Flight Center and is presented in paper 19. As a result of the analysis of these photographs, Mr. Lowman concluded that potentially useful geological and topographical information could be obtained from all terrain photographs taken during orbital flight. The quality and resolution of these photographs approached or equaled that of the black and white exposures from the best rocket flights.

*Dim–light photography.*—A dim–light photographic experiment sponsored by the School of Physics, University of Minnesota, was carried out for the MA–9 mission to obtain photographic data on two dim–light phenomena best observed outside the earth's atmosphere. These phenomena are the so–called zodiacal light and the night airglow. Photographs of the zodiacal light were needed to assist in determining its exact origin, geometric distribution, and relationship to solar radiation and flare activity. Data on the airglow were needed to define the layer further and to provide information on the solar energy conversion process occurring in the upper atmosphere.

Figure 12–11 shows a photograph of the 35–mm Robot camera as it was modified for this experiment. The camera was equipped with an automatic film advance and had a fixed lens with an equivalent speed of f/0.95. Exposures were timed manually, and the camera controls were simplified to improve operation by the astronaut in a pressure suit. Three small supports or "feet" (see fig. 12–11) were provided to aid the pilot in positioning the camera against the window for aiming.

Photographs, varying in exposure time from 1 to 30 seconds, of the zodiacal light were to begin immediately after sunset and were to cover the ecliptic region from sunset to about 30° of arc past sunset. Photographs of the airglow layer were to be taken periodically over an entire night orbital pass with exposures varying in duration from 10 to 120 seconds.

Unfortunately, the zodiacal–light sequence yielded very little useful data since all of these photographs were underexposed. A small de-



FIGURE 12–11.—Modified Robot camera used for MA–9 dim-light photography.

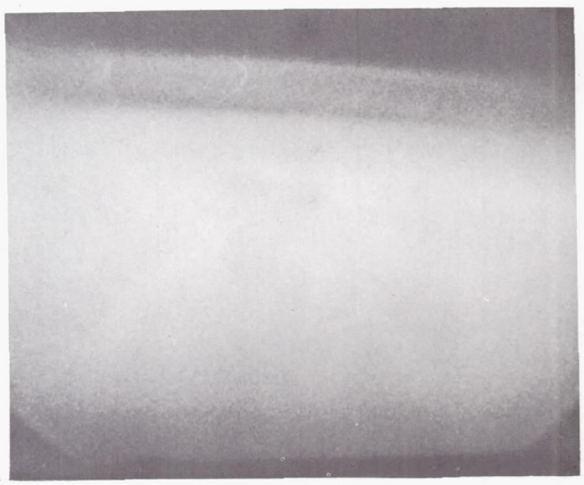


FIGURE 12–12.—Photograph of the airglow layer taken by Astronaut Cooper on the MA–9 flight.

lay in initiating the sequence or an error in exposure time could have caused these unsatisfactory results since the gradient in zodiacal light intensity varies quite rapidly near the sun.

The airglow photographs, however, were of quite usable quality. A representative photograph from this experiment is shown in figure 12–12. Preliminary analysis of these photographs by Dr. Edward P. Ney and associates at the University of Minnesota has shown them to be useful in determining surface brightness of the airglow layer. These photographs also were found to be valuable for assessing the height of the layer with varying latitude, in measuring the angular width of the band, and in determining angular displacement above the earth's horizon. Considerably greater discussion of this phenomenon is presented in paper 19.

### Radiation Experiments

Some form of radiation measurement has been included on all Mercury space flights to record the dose received by the astronaut and to furnish experimental information on the space radiation environment over the Mercury altitude profile.

Generally, data obtained during these experiments were measured by the following method:

(1) Studies in which film or lithium–fluoride thermoluminescent detectors were used to measure the dosage to the astronaut.

(2) Emulsion packs and ionization chambers to measure the radiation level inside the spacecraft.

(3) A package containing Geiger–Mueller tubes to measure the electron flux external to the spacecraft.

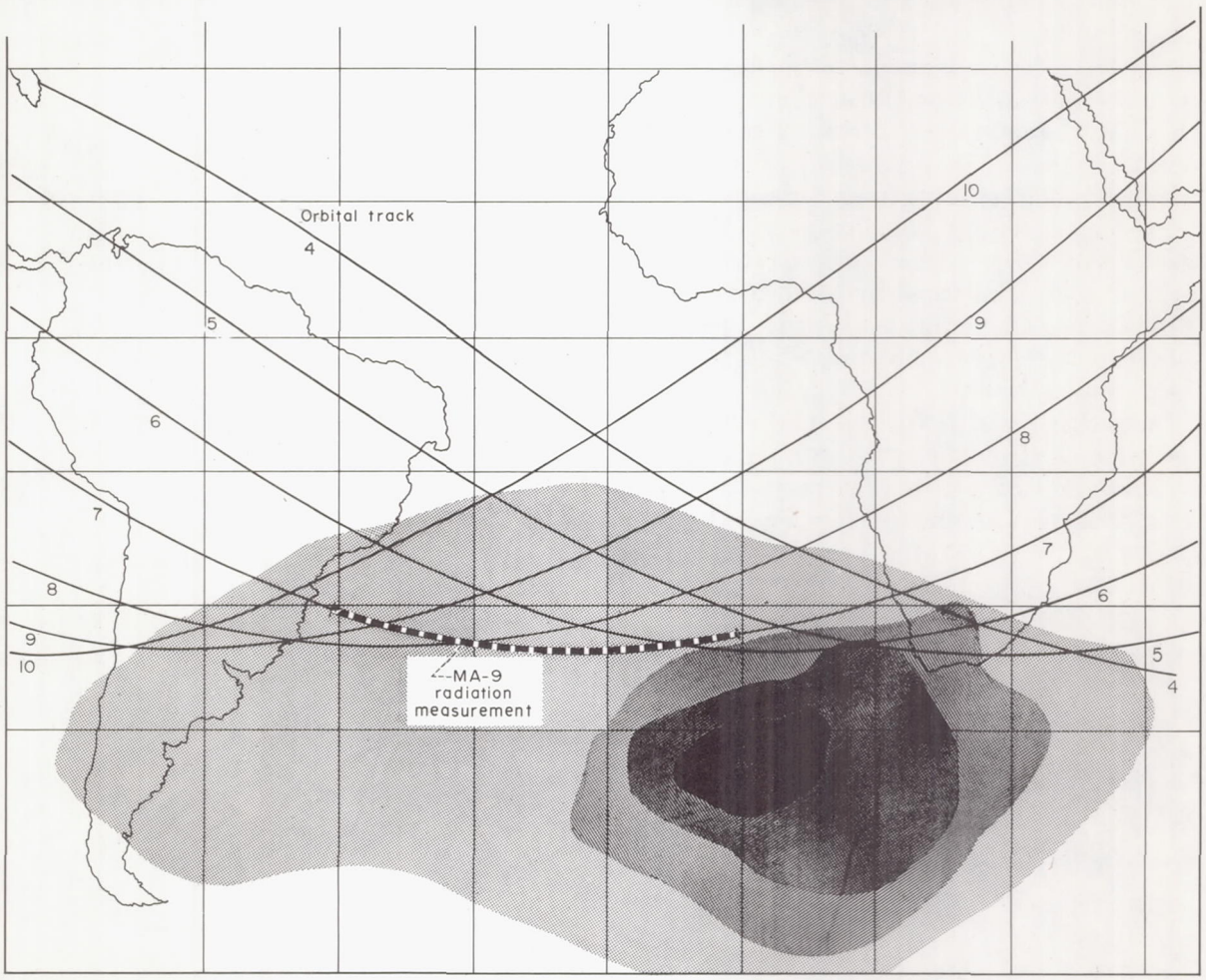



FIGURE 12–13.—Variation in predicted flux at 100 km in the anomaly of the earth's magnetic field over the South Atlantic on the MA–9 flight. Increased flux density shown by increase in amount of shading.

Film badges and thermoluminescent detectors used to monitor the electron dose to the astronaut were mounted on the helmet and on the chest and thigh of the astronaut's undergarments on each of the final two manned orbital flights. Evaluation of these detectors has shown that the radiation dosage received by the astronaut is quite low, less than that normally received by a man from cosmic radiation in 2 weeks on the surface of the earth.

Emulsion packs carried on the MA–8 and MA–9 flight at several locations inside the spacecraft as well as an ionization chamber mounted on the spacecraft hatch were used to assess the radiation level inside the spacecraft. Data obtained from these devices generally agreed with results derived from the film badges and showed a very low radiation level inside the spacecraft.

Radiation measurements were made on the MA–9 flight to map the electron flux in an anomaly of the earth's magnetic field occurring over the south Atlantic Ocean where the radiation levels are expected to reach a peak in the Mercury orbit. (See fig. 12–13.) Variation in between radiation intensity is indicated by the variation in shading in this region. Measurements were taken in this region on the seventh orbital pass as indicated by hatched region on this figure. Operational problems interfered to some extent with completing all of the scheduled measurements.

A package with two Geiger–Mueller tubes were mounted on the spacecraft retropackage as shown in figure 12–14 to measure these data. One tube was collimated to view along the spacecraft roll axis over a solid angle of approximately 0.8 steradian as illustrated in figure 12–14. The other tube viewed essentially a hemispherical area about a direction 40° below the roll axis.

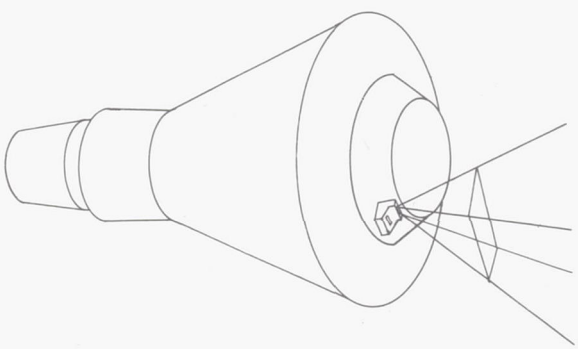


FIGURE 12–14.—Geiger-Mueller tube installation on the MA–9 spacecraft.

The uncollimated tube was shielded to reject all electrons having energy levels less than 2.5 mev to avoid saturation, and because the radiation level in the anomaly was much lower than anticipated the shielded tube was never energized sufficiently to record usable data. Usable data were recorded by the collimated tube.

Results obtained from these Gieger–Mueller tubes and emulsion package measurements from both the MA–8 and MA–9 missions, summarizing the decay of the artificial electron belt created by the July 1962 atomic explosion, are shown in figure 12–15. The solid curve defines the decay in percent of initial flux based on unpublished riometer data of Dr. Gordon Little of the National Bureau of Standards (NBS). The environmental measurements obtained on both the MA–8 and MA–9 flights are also identified

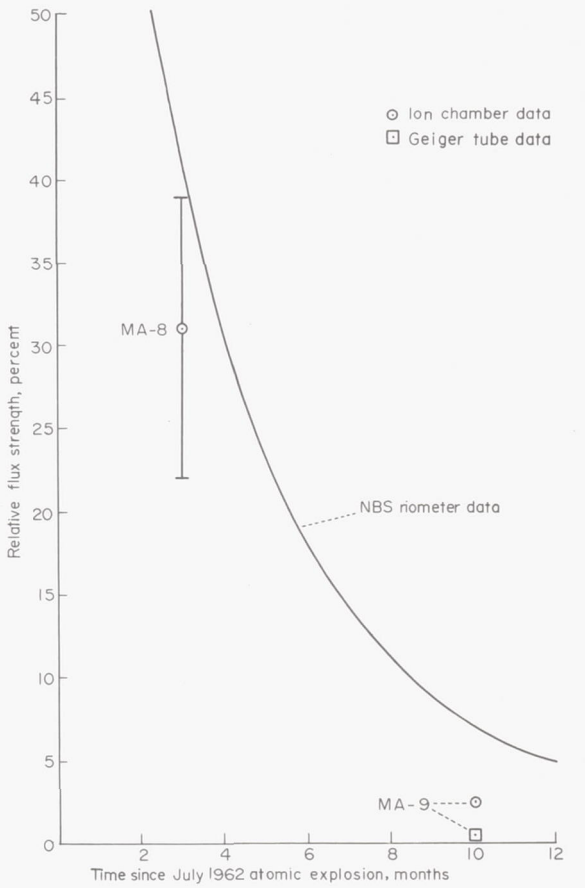



FIGURE 12–15.—Results showing artificial electron flux decay in the magnetic anomaly over the South Atlantic.

in the figure. The electron belt is shown to have decayed as predicted by several orders of magnitude during the time period between MA–8 and MA–9 flights, possibly because of atmospheric collisions or other processes.

### Tethered Balloon Experiment

A 30-inch mylar inflatable sphere was packaged in the antenna canister of both the MA–7 (see ref. 1) and MA–9 Mercury spacecraft. These balloons were to be ejected, inflated, and towed at the end of a 100-foot nylon line through one orbital pass to measure the drag experienced by the balloon throughout the orbit. The measured drag could then be readily converted into air density over the Mercury altitude profile. In addition, it was hoped that the astronaut could obtain some sightings yielding visual data on objects in close proximity to the spacecraft.

The design, construction, and qualification of the equipment used on this experiment were carried out by the NASA Langley Research Center. The components of the equipment are shown in figure 12–16. The results of this experiment conducted during the MA–7 flight are contained in reference 1. Briefly summarized, the balloon was deployed satisfactorily but was only partially inflated; hence, little useful data were obtained on this flight.

By a thorough investigation of the MA–7 failure, it was concluded that the balloon failed to inflate because one of the seams connecting the many gores comprising the balloon skin pulled apart.

The experiment was believed to have been of sufficient value to be repeated on a later Mercury flight; therefore, new equipment was developed and qualified for the MA–9 flight. Careful control of balloon construction was maintained throughout the development program and numerous deployment and inflation tests were conducted by the Langley Research Center to insure the quality of the device. These tests were conducted with the flight equipment under conditions which closely simulated the space environment without a single failure. Numerous squib firings were made, without a single failure, to insure that either one or both of the squibs used to unlatch the cover of the canister would accomplish this task. The assembled unit was carefully checked after installation on the spacecraft and was found to be satisfactory. It was, therefore, believed that this experiment was well qualified for flight, but unfortunately the balloon failed to deploy in flight. Failure was attributed to some malfunction in the squib-firing circuit that released the hatch cover of the balloon canister. The exact cause of this malfunction could not be determined because the circuit was contained in the spacecraft antenna canister which is jettisoned prior to landing.

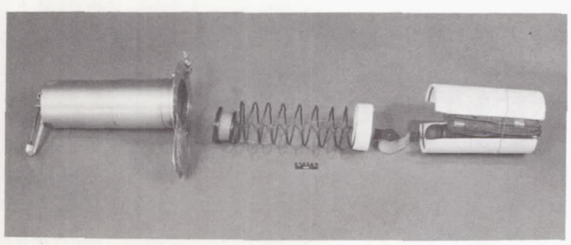


FIGURE 12–16.—Balloon canister assembly.

### Miscellaneous Studies

*Study of liquid behavior at zero gravity.*—An experiment sponsored jointly by the NASA Lewis Research Center and the NASA Manned Spacecraft Center was developed to examine the behavior of fluids of known properties in a weightless state by using a given container configuration and was flown on the MA–7 mission (see ref. 1). Basically, this experiment was intended to provide data that would complement and extend work already carried out at the Lewis Research Center. Data obtained from this study were expected to provide information relating to the tankage and fuel transfer requirements on future space missions.

The results of this experiment are well defined in reference 1 and other NASA publications dealing with this subject. It need only be noted here that the limited results obtained on this experiment generally tended to verify past experimental and theoretical data obtained from laboratory studies.

*Study of various ablative materials on a Mercury flight.*—Several advanced ablative materials were flown on the cylindrical section of the MA–8 spacecraft to evaluate the thermal performance of each. These materials were

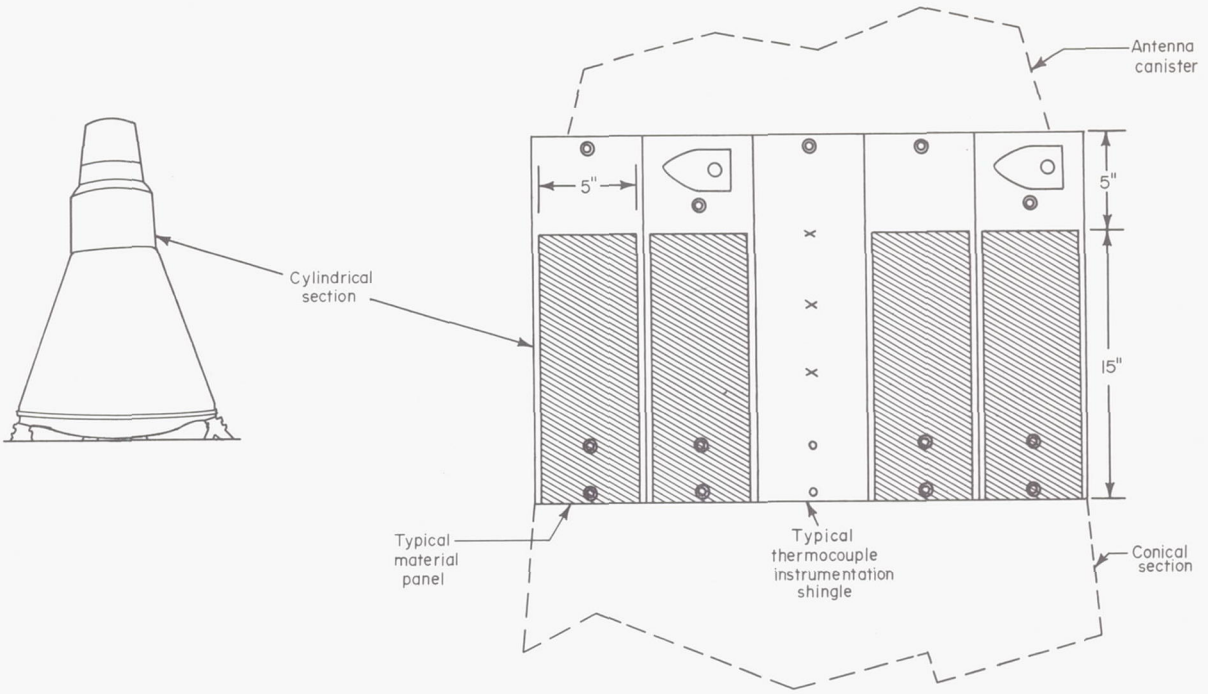



FIGURE 12–17.—Location of ablation panels on the Mercury spacecraft used for the MA–8 flight.

located as shown in figure 12–17. Each ablative panel was 15 inches long and 5 inches wide. Each sample was centered on a beryllium shingle and was attached to the shingle at the cone–cylinder junction of the spacecraft. The materials were bonded to each of these shingles, and temperature–sensitive paints were applied to the rear face of the shingles to assist in determining the temperature profiles present along the ablation panels during reentry. (See ref. 2.)

Upon completion of the MA–8 flight, each strip of ablative material was removed from the spacecraft and examined to determine char depth and temperature distribution and to examine the material for delaminations, pitting, and cracks.

It was not possible to compare the panels collectively because of significant circumferential variation in heating around the cylindrical section, probably caused by a spacecraft angle of attack of 2° during high heating. As expected, all samples showed an increasing thermal exposure and char depth with length aft (away from the blunt end) along the specimen. No material, regardless of the heat rate to which it was exposed, showed any marked superiority in performance over that of the other specimens although the elastomeric materials did prove superior to hard ablation materials in limiting the growth or delamination of intentional cutouts. Surface effects and imperfections noted during preflight ground testing were also evident during the postflight analysis, but to a lesser extent. However, the scaling effect when comparing the relatively large specimens flown with those tested in a ground facility has not been established.

*Micrometeorite studies.*—Examination was made of all the spacecraft flown on manned orbital flights during the Mercury Project for evidence of micrometeorite impact encountered in orbit. Macroscopic surveys were made of the beryllium shingles and the window of the MA–6, MA–7, and MA–8 spacecraft before and after flight in an effort to determine if any micrometeorite impacts could be detected. Microscopic

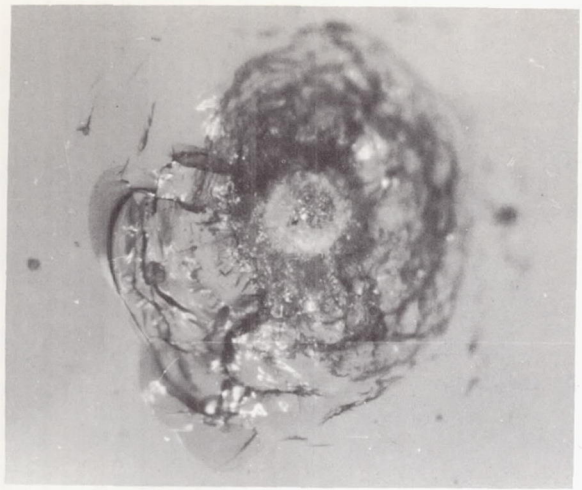


FIGURE 12–18.—Photograph of the surface pit on the window of the MA–9 spacecraft. X42, top and bottom lighted.

surveys were made of the areas in which any indications of impact were noted. As a result of these examinations, no evidence was found that could be construed to be a micrometeorite impact.

Microscopic mapping of the vycor window of the MA–9 spacecraft was performed before and after the mission. During the postflight survey, one small surface pit was detected on the outer surface of the MA–9 spacecraft window. A photograph of this pit is shown in figure 12–18. This surface pit has the circular shape, depth to width ratio, and general characteristics of a hypervelocity impact in basalt. Further analysis is in progress to ascertain whether or not the pit resulted from a micrometeorite impact or was caused by spacecraft debris encountered during reentry.

## References


1. BOYNTON, JOHN H., and FIELDS, E. M.: *Spacecraft and Launch–Vehicle Performance.* Results of the Second United States Manned Orbital Space Flight, May 24, 1962. NASA SP–6. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 1–14.
2. BOYNTON, JOHN H., and FISHER, LEWIS R.: *Spacecraft and Launch–Vehicle Performance.* Results of the Third United States Manned Orbital Space Flight, October 3, 1962. NASA SP–12. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 1–11.

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# 13. FLIGHT DATA REPORTING

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## Summary

During the progress of the Mercury Project an effective method evolved for the postflight data processing, analysis of systems performance, and timely reporting of the results of the analyses. This method was a compromise between the conflicting requirements of completeness, clarity, and technical accuracy on the one hand and an early publication date on the other. It was learned that there is a need for extensively planning the report preparation effort and establishing procedures for expediting data processing in order to provide engineering data rapidly and in readily usable forms. It was also learned that for a report to be effective, it must be factual, carefully written, and edited.

## Introduction

The success of a complex technical endeavor, such as Project Mercury, depends to a great extent on the ability to analyze and report rapidly the very large amount of information which is generated. Rapid availability of information was essential to maintain the Mercury schedule, since the developments from any mission might need to be implemented for subsequent missions.

Extensive planning and scheduling was done to facilitate the acquisition and preparation of data. The flight data and information were examined to determine weaknesses and malfunctions in the performance of manufactured systems and human organizations, and to verify the proper performance of these systems and organizations. When these analyses had been made, they were summarized and a brief, accurate, and factual report was written so that the management of the program would have available all significant information to aid in making necessary decisions. This primary report of the results for each flight, the Postlaunch Memorandum Report, is discussed in detail in this paper.

This paper describes the techniques employed to process raw data into usable form, to obtain the overall analysis of mission results, and to report those results to management.

The processing of certain data, such as the trajectory information from the radar tracking network, and the numerous reports that were made by the spacecraft contractor and other supporting organizations after each mission, are not discussed in this paper.

## Scope

### Data Sources

The flight data with which this paper is primarily concerned were those data available from the spacecraft onboard tape recorders since these tapes contained the most complete data and were available for quick processing. The onboard tape included information pertaining to the operation of the spacecraft systems, the astronaut's physiological conditions, the pilot's voice communications, and other special measurements. A list of typical measurements is presented in table 13–I. Most of this information was also transmitted to the ground and recorded by range network stations, and some of the information was displayed in real time to monitoring personnel. These range-recorded data have often become critical to the analysis conducted after the flight, in addition to serving as a complement for the onboard recorded data. Since the spacecraft sank in deep water following the Mercury-Redstone 4 (MR–4) flight, the onboard-recorded data were not recovered, and the range-recorded data became the only source of

information from this flight. In the Mercury-Atlas 9 (MA–9) mission, the tape supply of the onboard recorder was insufficient to provide continuous recording for the entire mission; therefore, the range-recorded data were used to supplement the onboard-recorded data.

*Table 13–I.—List of Typical Recorded Flight Measurements*

- Flight accelerations in three axes
- Physiological measurements
  - Body temperature
  - ECG
  - Blood pressure
  - Respiration rate and depth
- Events (approximately 20)
- Environmental control system
  - Oxygen supply pressures
  - Suit pressure and temperature
  - Cabin pressure and temperature
  - Static pressure
  - Heat exchanger temperatures
  - Oxygen and carbon dioxide partial pressures
- Electrical system
  - Instrumentation reference voltages
  - Main, standby, and isolated bus voltages and current
  - Fans and ASCS bus a-c voltages
  - Inverter temperatures
- Communications system
  - Command receiver signal strength
  - Command receiver on-off
- Reaction control system
  - Automatic and manual fuel pressures
  - Fuel line and thruster temperatures
- Stabilization and control system
  - Control stick positions
  - Spacecraft attitudes (gyros)
  - Spacecraft attitudes (horizon scanners)
  - Automatic system high and low thruster actuation
  - Spacecraft attitude rates
- Onboard time
  - Time since launch
  - Time of retrosequence initiation
  - Time since retrorocket ignition
- Structural heating
  - Heat shield temperatures
  - Retrorocket temperatures
  - Shingle temperatures
- Experiments
  - Balloon drag
  - Radiation flux density

The pilot's comments recorded during the mission and in postflight debriefings were an important source of information. This information was used in many cases in defining the performance of the spacecraft or launch vehicle systems when the measured data were lacking or permitted ambiguous interpretations. Even more important, the pilot's debriefings and reports were the only source of information regarding many of his observations.

Additional sources of information during various flights were provided by a variety of cameras which were carried onboard the spacecraft and used to photograph the instrument panel, the astronaut, the view through the spacecraft window, and, for the unmanned Mercury-Redstone and Mercury-Atlas flights, the view field of the periscope.

### Analysis

The analysis of the flight data began at the launch site during the flight and continued until the Postlaunch Memorandum Report (PLMR) was completed. The analysis of problems requiring study beyond the publication date of the PLMR was continued to completion, and the method of reporting the final results is discussed in the following section of this paper.

### Reporting

The results and analyses for each mission were (or will be) presented in five formal NASA reports, which are listed in table 13–II.

The first of these reports, issued in the form of a telegram approximately 2 days after the end of the mission, gave a broad overall summary of mission results as they were known at that time. For most of the flights this report was issued within a day of the end of the mission in order to disseminate the available information as quickly as possible; however, for the MA–9 flight it was found that more time was needed to gather and summarize significant information, and as a result this telegram was issued 3 days after the end of the flight. This first report had a very limited distribution, going only to those organizations directly concerned with the mission.

The second of these reports, also issued in the form of a telegram approximately 6 to 10

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*Table 13–II.—Mercury Postflight Reports*

| Type of Report | Approximate period to report completion, days[a] | | | | | | Classification | Content |
|---|---|---|---|---|---|---|---|---|
| | MR–3 | MR–4 | MA–6 | MA–7 | MA–8 | MA–9 | | |
| Telegram (preliminary) | 1 | 1 | 1 | 1 | 1 | 3 | Confidential | Broad overall summary of mission results as known at that time. |
| Telegram (Interim) | [b] | [b] | 7 | 7 | 9 | 10 | Confidential | Updated version of preliminary telegram describing status and problem areas. |
| Postlaunch Memorandum Report (PLMR) | 11 | 10 | 11 | 14 | 19 | 26 | Confidential | Contains all detailed spacecraft data and description of resolutions of problem areas or status of investigations of unresolved problems. This report contains 95 to 98 percent of all important information that would come from the mission. |
| Public Release[c] | 30 | 30 | 44 | 80 | 90 | 130 | Unclassified | Summary report of mission results for distribution to the public. |
| Technical Memorandum (TM) or Working Paper (WP) | 41[d] | 60[d] | [e] | [e] | [e] | [e] | Confidential | Official presentation of detailed analysis of mission. This report is an updated version of PLMR with latest information and in a format suitable for distribution to the technical community. |

[a] Elapsed calendar days from end of mission to completion of final review and editing.
[b] Interim telegrams were not used for MR–3, and MR–4.
[c] See references 1 to 5 and this document.
[d] WP.
[e] TM, in preparation.

days after the end of the mission for the more recent manned missions, had a dual purpose. The first purpose was to show any significant changes to the information contained in the first telegram, and the second purpose was to describe the status of the analysis of the mission results at that time with emphasis on any problem areas. Any problems encountered during the mission were of particular interest since such problems might have a direct effect on the schedule or the prepartions for the next mission; as a consequence, little time was spent in this second telegram discussing systems that had exhibited satisfactory performance. This telegram had the same limited distribution as the first telegram.

The third type of report, the PLMR, was bound into one or more volumes depending on the amount of information contained. This report was completed in a period of 10 to 26 days, and contained 90 to 95 percent of the significant information that would come from the flight. The amount of time needed to complete the report depended primarily on the amount of data collected during the mission. This report was the most important of the postflight reports in terms of its usefulness to the program management in the timely prosecution of the program. This report had a relatively wide distribution within NASA.

The fourth of these reports was a summary of the important highlights of the mission, with classified information deleted to permit release to the public (see refs. 1 to 5).

The fifth of these reports was issued as a working paper (WP) for the Mercury-Redstone manned flights. The WP was used for rapid dissemination of information, and the format and quality of presentation was not suitable for general distribution outside NASA. For the manned Mercury-Atlas flights the fifth report will be issued as a Technical Memorandum (TM), suitable for distribution outside NASA. These TM's (one for each mission) will be distributed within the scientific community after publication. Both the WP's and TM's contained, or will contain, the significant information published in the PLMR's plus any additional results that became available after publication of the PLMR.

The remainder of this paper will be limited to discussion of the preflight and postflight activities related to the PLMR.

## Report Planning and Organization

### Planning

In the early days of the Mercury Project, the planning and organization for postflight analysis and reporting of mission results did not need to be very elaborate, and these plans were made known to the participants on an informal verbal basis. A NASA Project Engineer was responsible for all aspects of a particular flight.

For the first few flights, such as the pad-abort flight and early Little Joe flights, the flight time was measured in minutes, with a relatively small amount of data collected. The analysis and reporting effort, though intensive, was correspondingly small in terms of the number of people involved and the total amount of time spent when compared to the later orbital flights. All of this analysis and report preparation was done at the launch site at Wallops Island, Virginia.

The plans for organizing the analysis and reporting efforts continued on an informal basis through the Little Joe phase of the Mercury Project and extended into the Redstone and Atlas phases. As the flight time, amount of data, and number and complexity of the systems to be analyzed increased, and the number of personnel grew, it became difficult and then virtually impossible to disseminate by verbal discussions and telephone calls the work assignments, schedules, changes in plans, et cetera, to the participating personnel. To circumvent these difficulties, informal memorandums came into increasing use. As a result, prior to the MA–5 flight a data processing, analysis, and reporting schedule was prepared for the first time, and was in the form of a five-page memorandum. This memorandum, which was distributed to all participating personnel and to the necessary organizations, outlined the schedule for data processing and noted when and where various types of data would be available, the assignment of individuals to various sections of the PLMR, and the detailed sched-

ule for the writing and editing of the various sections of the report. This procedure was found to be effective, and the memorandum grew steadily in scope and detail as the need for additional information became evident through the subsequent orbital missions. For the MA–9 mission this memorandum had grown to 31 pages. It contained such things as personnel assignments, data-availability and report-preparation schedules, schedule of the pilot's postflight activities including debriefings, locations of various facilities where people would be working on data analysis and report preparation, and a definition of the responsibilities and work scope of the organizational elements participating.

### Organization

The organization of the effort of the analysis and reporting went through a continuing evolution as the Mercury flight program proceeded, up through the PLMR for the MA–5 flight. By this time, a method of organizing the effort had evolved which was satisfactory in producing in a short time a reasonably complete and factual report, written with sufficient clarity.

As in the case of the dissemination of the plans, the organization of the effort for analysis and reporting was relatively small and informal for the first few flights of the Mercury Project. The effort was headed by the NASA Project Engineer for that particular flight, who largely determined the scope of the analysis effort and edited the various sections of the PLMR.

During a part of the early phase of the Mercury-Atlas and Mercury-Redstone flights, as the analysis and reporting became more complex because of the increasing complexity of the flights, additional NASA organizational elements became more deeply involved in the analysis and reporting. Because of this, there was a movement to create an editorial board consisting of one member from three or four of the major organizational elements involved, with each member having equal responsibility and authority. One of the early Mercury-Atlas reports was prepared under the direction of a three-man editorial board but this arrangement was quickly found to be unworkable mainly from the standpoint of settling policy and procedural questions that inevitably arose during each analysis and reporting effort. The method of managing this analysis and reporting effort reverted for the next flight to an arrangement with a single organization responsible for the effort. This arrangement was kept throughout the remainder of the Mercury Project.

Prior to the first manned Mercury–Redstone (MR–3) flight, the increasing responsibilities for data analysis and reporting had resulted in the assignment of key technical personnel to duties on editorial boards or Senior Editorial Committees headed in each case by the appropriate project engineer. The function of this editorial board was to actively participate in the planning and monitoring of postflight systems testing, data analysis, and editing of sections of the report.

The membership of the editorial board during the early flights changed from flight to flight, but usually one or more members were the same for at least two flights in order to provide continuity and some consistency of effort. The PLMR editorial board for MA–5 and a majority of the systems-performance analysts were for the most part the same people who had served in those capacities for the PLMR for MA–4, and these personnel assignments remained relatively constant for the remainder of the Mercury Project.

As an example of the organizational arrangement of the reporting team, figure 13–1 shows

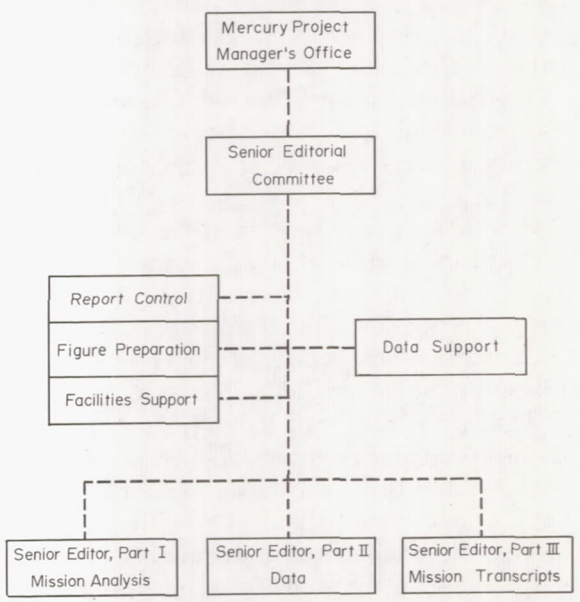



FIGURE 13–1.—Functional relationships for editorial and support personnel.

the major elements of the task organization for the MA–9 report. The Senior Editorial Committee members and the supporting members were drawn from various elements of the NASA Manned Spacecraft Center, and for the period of the PLMR preparation the members reported functionally to the Chairman of the Senior Editorial Committee. As each member's part of the task was completed, he returned to his parent organization.

The functions of the elements shown in figure 13–1 are described briefly below:

The Manager's office provided the overall directions for the postflight test program. In addition, the Manager's office reviewed the PLMR for technical accuracy, completeness, and policy, immediately prior to printing.

The Senior Editorial Committee comprised the senior editors of the separate parts of the report and the MA–9 backup pilot and these persons directed and coordinated the detailed efforts of postflight testing, analysis, and reporting. The members of this committee also performed a continuous review and editing of the individual sections of the report in an effort to maintain continuity and technical agreement among the sections of the report. The Chairman directed the planning of the overall reporting effort prior to flight, provided intermediate and final editorial reviews of major portions of the report, acted as official representative of the Manager's office, and coordinated the report preparation effort continually through the Senior Editorial Committee.

The Senior Editor of Part I, *Mission Analysis*, gave overall direction to a team of subeditors and system specialists who performed postflight analyses, and tests required to explain inflight systems malfunctions. These sub–editors participated as required with the system specialists in the analysis of the data from the mission and the preparation of this part of the report which summarized the overall results of the mission.

The Senior Editor of Part II, *Data*, gathered data-processing requirements prior to flight, planned and provided data processing, presentation, and distribution. In addition, he directed the analysis of data quality and was responsible for the preparation of the flight data section of report.

The Senior Editor of Part III, *Mission Transcripts*, managed the preparation and editing of the various voice transcripts for both flight communications and post flight debriefings, and planned and conducted the postflight scientific debriefing.

The functional organization shown in figure 13–1 was used in the overall management of the mission analysis and reporting. A more detailed breakdown of the functional organization of the Part I effort is shown in figure 13–2 to illustrate the depth of organizational detail needed. The personnel for each assignment were drawn from throughout the Manned Spacecraft Center, with assistance from other NASA centers and contractors as needed.

The need for a well-planned organization can best be illustrated by noting that for the MA–9 PLMR analysis and reporting effort, contributions were made by personnel from fourteen NASA organizations, four contractor major organizational elements, numerous organizations of the Department of Defense, the U.S. Weather Bureau, and several colleges and universities. During this analysis and reporting period, approximately 20,000 man-hours were spent by approximately 130 people in producing a 1,000-page 3-volume report in 26 days.

## Analysis of Mission Results

### Data Processing

To meet the needs for processed data to be used for analysis and reporting purposes in the shortest possible time, several decisions were made as experience was acquired. The maximum use would be made of electronic data processing to provide data in the most readily usable form. Where necessary, manual effort would be used, in addition, to provide the data in a format which would require the least additional manipulation on the part of the analyst. In processing the data the initial format would be made as nearly as possible of a quality that would be suitable for final report use. In this way the data would be prepared for its various types of usage by photographic reproduction rather than by recomputing, rescaling, and replotting. The requirements of the analysts would be determined as far as possible well in advance of the generation of the data in order that the parameter arrangements, scale selection, and priority might be determined. As

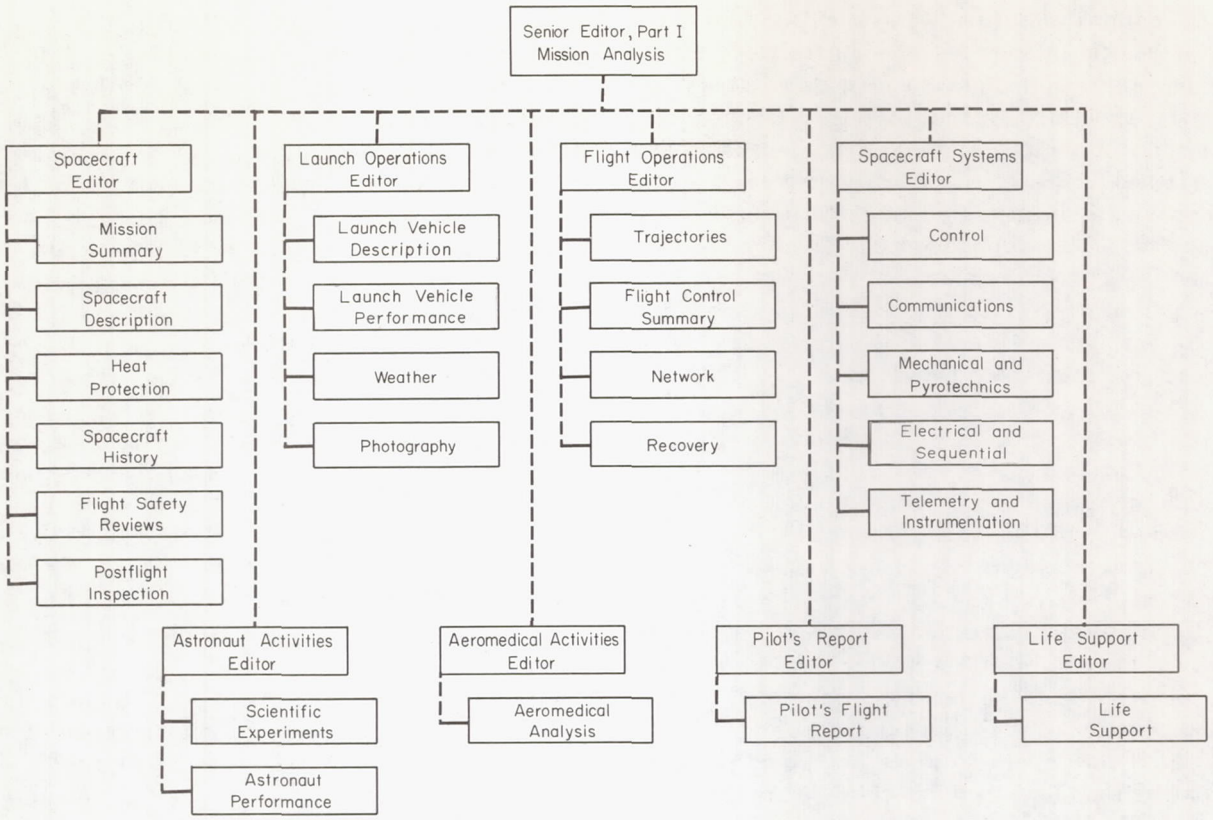



FIGURE 13–2.—Typical functional organization for Part I of report.

successive flights were made, formats were standardized to enable comparison between the data from various flights, thus providing an additional constraint.

When the electronic data-processing method became operational, a decision was made to process all applicable data during one effort for each flight. To permit parallel processing, several copies of the onboard tape were prepared. If the processing results were to be accurate, the tape copying had to be carefully checked. To accomplish this, oscillographic records were prepared from the master and tape copies. These oscillographic records were visually compared. If visual inspection indicated any differences, the records were compared by superimposing records over a back-lighted glass plate. If there were any significant differences between the records, the tape copy was rejected.

The automatic data-processing capabilities were not easily obtained. Data reduction processes may introduce errors at many points in the system. The accuracies of the basic spacecraft data system were sufficiently high to require more care in the reduction of the data than was the general practice. Utilization of experiences gained from the preceding flights were required to obtain the product quality and processing efficiency attained on MA–9. The Mercury experiences have indicated that significant improvements in quality and efficiency can still be attained.

The initial effort to use automatic processing methods was begun with the off-the-pad abort and Little Joe tests. In this effort, time-history plots were prepared from telemetered data by using analog plotting methods. The differences between the oscillographic-type records and the analog plots were that the time axis was compressed and engineering units could be read from the analog plots. The compression of the time axis accentuated the scatter in the data, however, and the processing methods themselves added some additional scatter. As a result, the electronically processed data lacked the desired accuracy. In these cases, the analysts continued to use the oscillographic recordings as a primary source of data.

To improve the quality of the processed data, various techniques of reducing scatter (filtering) were applied and some of the plotted data were smoothed by line fairing. The requirements for the postflight analysis were still not satisfied by the electronically processed data, since vital information might still be lost as a result of data filtering or line fairing. Nevertheless, it was recognized that here was a method which provided all of the flight data in a standard format and in a compact form suitable at least for indicating major trends.

The use of digital computers for the data processing increased as the Mercury Project continued. At first the computer-processed data were used for checking analog plots and later some of the data were plotted from computer-prepared cards by using a small card-fed digital plotter. The data obtained from the digital plotter were hand faired to provide a trace comparable to the analog processed data.

The greatest "bottleneck' 'encountered in data preparation was in the plotting of data. Initially, one analog plotter was used in preparing the Mercury data. Only one parameter could be plotted at a time and the time to plot was the same as real time. At the time of the MA–5 flight, four analog plotters were in use and they were operated at a speed of eight times real time.

Because of the difficulty in making corrections to the analog plots when graph paper was used, it was decided to plot on a clear plastic film. This innovation speeded the plotting process by making it possible to erase an error rather than replot several parameters on a new page, and by providing a means for superimposing analog plotted data onto digitally plotted data for related parameters. The plastic film was also less affected by temperature and humidity changes than was graph paper.

It was not until the MA–6 mission that digital computers and digital plotters became the primary processing tools. Prior to this mission, the computer was used to prepare tabulations of data in engineering units, and some digital plots were prepared. But now a faster general purpose computer and a magnetic-tape-fed plotter were available. It became the exception rather than the rule to use analog plotters. With these faster tools available, it was practical to sample the data and it was much easier to apply nonlinear calibrations. By this time the electronically processed data had become acceptable, since comparisons of both methods had shown them to be equally accurate.

Also by this time most of the data requirements had become well established through discussion with systems analysts. These requirements included a definition of the parameters of interest, their grouping for analytical purposes, the time periods of concern, the plotting scales, and the priority of processing. Thus by the time of the first manned orbital flight the basic equipment, methods, and standards were established. Further improvements were made but these were improvements in methods rather than equipment. The most important of these improvements were:

(1) The plotting density was reduced, thus speeding up the plotting and improving the appearance of the plot. This required more thorough checking to insure against the loss of data during transients. To overcome this fault a variable plotting density was used; that is, each data point was compared with the previous data point. If the difference was more than a predetermined amount, both the previous point and the present point were plotted. If the difference was less than the predetermined amount, a point was plotted at fixed intervals of time.

(2) Instead of rewinding a plotter tape to plot a second parameter on a page, time was saved by plotting the second parameter in reverse.

(3) Special photographic techniques were used to minimize replotting. Analysis plots, normally made with expanded horizontal scales for detailed work, were photographically reduced in the horizontal axis without reduction in the vertical axis. Thus working plots were compressed in length for use in the reports without it being necessary to replot.

(4) A developmental program was initiated to permit the determination of heart rate by digital means. Such a method became a necessity on the longer flights in order to obtain a complete time history of heart rate. The method developed provided the time between beats so that an average over any selected period of time could be obtained. Statistical treatment of these data was thus made possible.

(5) Much valuable information was voice-recorded during flight by the astronaut but its value was to a great extent dependent upon having an accurate knowledge of the time a statement was made. Early methods required that a typed transcript of the voice record be timed with the use of a stopwatch and the voice tape; this method was adequate for the short-duration flights. For the three-orbital manned flights, timing was accomplished by use of the typed transcript and an oscillograph record containing the voice patterns and time from lift-off in 1-second intervals. By simultaneously relating the voice transcript to the voice patterns while listening to the voice tape, an accurate time for each communication was determined. For the longer 6-pass and 22-pass orbital flights, a method was developed to automate this process to some extent. A magnetic tape recording of the voice, with spacecraft time recorded on a second track, was played while an operator followed the typewritten text. At the first word of each communication in the text, the operator pressed a switch to compute and record the time. This process permitted the rapid preparation of a complete and accurately timed transcript of all of the pilot's voice communications.

Figure 13–3 provides some statistics related to data processing for each flight. As may be noted, the number of data points processed increased rapidly for the longer duration flights; for example, 14 million data points were processed for MA–9. However, the total processing time was held nearly constant at 5 days as the productivity of manpower increased and procedures were improved. Figure 13–4 shows a comparison of the time required for manual processing as compared with semiautomatic and automatic data processing for a given sample of data.

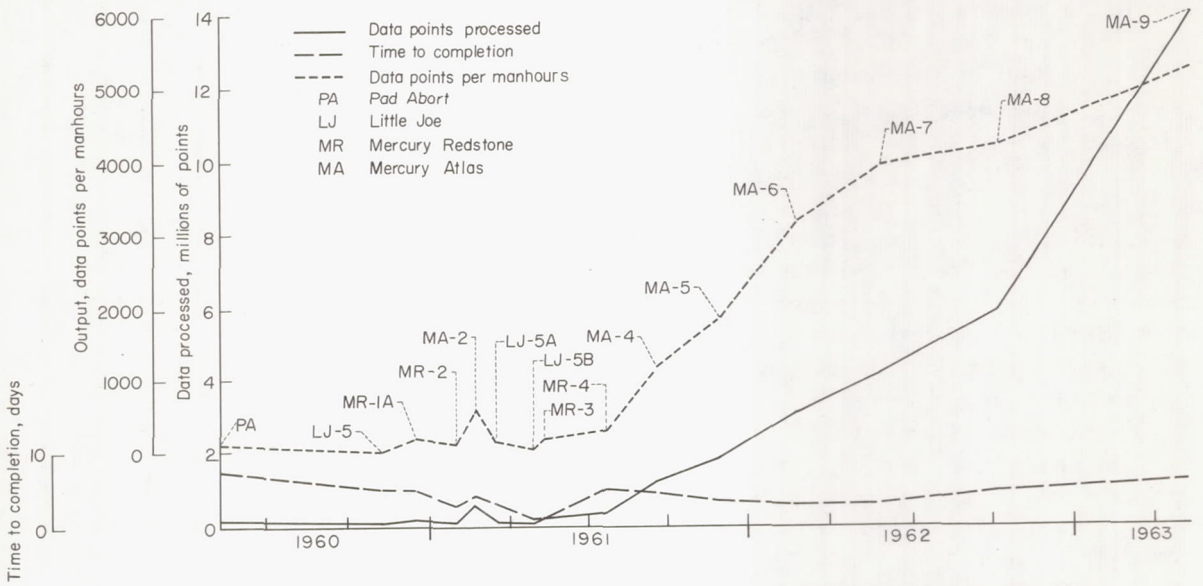



FIGURE 13–3.—Number of data points and processing time and rate for Mercury flights.

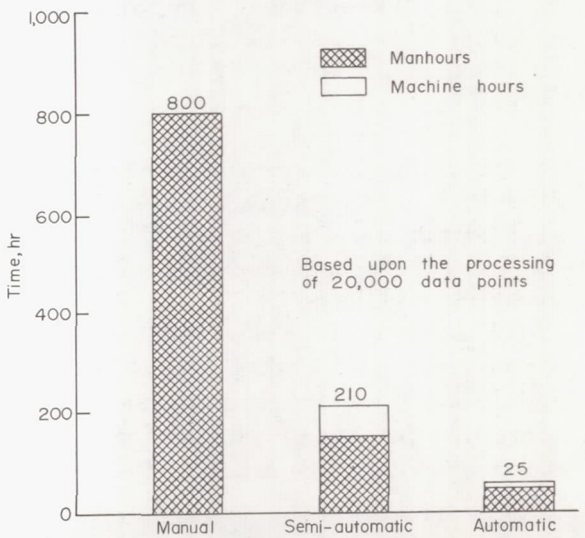



FIGURE 13–4.—Comparison of data processing techniques.

### Systems Performance Analysis

Most of the analysis of the Mercury systems' performance was made either at Wallops Island, Virginia, or Cape Canaveral, Florida, by NASA and contractor personnel who were responsible for the spacecraft preflight preparations and checkout and who were familiar with

these systems. The majority of the analysts had extensive experience in appropriate specialty fields.

As discussed in the Data Processing section of this paper, the major portion of the analysis of the early flights in the Mercury Project was made by using oscillograph records and hand-processing only those portions of the records that seemed to be significant. This hand-processing was time-consuming and several days were required to obtain an appreciable amount of data in the form of engineering units plotted against time. The conversion to electronic data processing was a most important factor during the later missions in permitting a rapid assessment of the mission results; without this electronic data processing, an incomplete analysis would have resulted if the same flight schedule had been maintained.

Toward the end of the Mercury Project a few data-comparison plots were prepared by using the electronically processed data. The purpose of such plots was to display time histories of the data for a particular system in a manner to allow very rapid comparison of the nature of the data on previous missions, showing at a glance the normal scatter and variations for both proper and improper system performance. The very limited amount of data prepared in this comparison-plot form was found to be an extremely useful tool for the analysts, the editors, and technical management personnel.

During the analysis and reporting period of the earlier flights, various types of work weeks were tried. The maximum number of hours worked by individuals was limited to 60 except in unusual circumstances. Work days ranging from 8 hours to 12 hours each, in combination with 5-day to 7-day work weeks, were utilized at various times. Experience showed that a schedule of 10 hours a day, 6 days a week, was a good arrangement to accommodate both the schedule and the participants' non-work-connected responsibilities.

In the analysis of the data, it was found that mission-oriented technical personnel were needed to supervise and direct the analysis and ensure that the overall effort would be integrated and fully coordinated. Few of the spacecraft systems could be analyzed as to their performance without considering the performance of other systems and the particular phase of the mission in question. For example, the temperature of the pilot's pressure suit was directly controlled by the operation of the suit heat exchanger; however, there was an indirect effect resulting from the temperatures in the spacecraft cabin, which in turn were affected by the operation of the cabin heat exchanger, the amount of electrical power being used (heat generation), and whether or not the spacecraft was in the sunlight or in the earth's shadow. Thus an analysis of the suit temperature could not be made without considering possible effects from these secondary sources of thermal disturbance.

### Postflight Tests

It was extremely important that immediate action be taken to determine the causes of any system malfunction or failure and the corrective action to be taken, since this information was necessary in order to support subsequent missions.

A person or group was assigned to determine the reason for the malfunction, and these investigations often became quite detailed and time-consuming. It was found to be necessary to require, whenever practical, that the malfunction be repeated with the same or an identical piece of equipment in laboratory tests to demonstrate that the cause of the malfunction was fully understood. In addition, when the flight equipment had been modified to preclude future malfunctions of that type, it was again demonstrated in ground tests with the simulated in-flight environment that the modification would do its intended job.

An example of postflight testing that could not be accommodated to the above philosophy of duplication on the ground of inflight malfunction was occasioned by the MA–1 inflight structural failure. It was impossible to duplicate this failure in ground testing, since the in-flight loads spectrum resulting from vibration, acceleration, aerodynamic drag, unsteady airflow, and noise could not be simultaneously applied in ground tests. The postflight investigation was therefore centered around tests on the structure of the front end of the launch vehicle, and on the adapter between the spacecraft and the launch vehicle. These tests, and a concurrent analytical investigation, did not conclusively define the exact cause of the failure but did show that strengthening the front end of

the launch vehicle and stiffening the adapter would be sufficient to prevent a similar failure. These changes were incorporated in the MA–2 mission, and the flight demonstrated that the modifications were satisfactory.

### Report Preparation

The preparation of the PLMR actually began just prior to the mission when some sections of the report that dealt with preflight activities were written. The main body of the report containing the sections of technical significance was generated during approximately the last 5 to 10 days prior to issuance of the report. During this time, the rough drafts were prepared and examined for accuracy, completeness, and absence of conjecture, by appropriate members of the report editorial staff.

As in the case of data analysis, it was found that mission-oriented technical personnel were indispensable in performing the editing functions. The editors were technically experienced personnel and most had degrees in appropriate specialized fields of study. They were temporarily relieved of their various technical duties in their organizations to serve as editors. There was never any attempt to use non-technical people as editors of technical parts of the PLMR, since the nature of the editing task was such that the use of technical personnel in this function was mandatory .

The experiences in the PLMR reporting indicate that three main factors contributed heavily to the rapid completion of the reporting phase:

(a) All reporting participants were relieved as completely as possible of their day-to-day responsibilities so that they could devote full time to the reporting task. In addition, when possible they were physically relocated to a place away from their usual duty locations in order to minimize distraction by non-reporting duties.

(b) A steady and intensive work week schedule was utilized, consisting of approximately 10 hours per day, 6 days per week.

(c) The editors exercised close and constant supervision of reporting personnel in their tasks of writing the sections of the report, with emphasis on the need for completeness, clarity, accuracy, and absence of conjecture or speculation.

It was quite difficult, of course, to separate key technical personnel completely from day-to-day duties, since these duties needed their continuous attention. However, it had to be done to a large extent, or the postflight analysis for a mission would have proceeded at a relatively slow pace and the program schedule could have suffered. The steady and intensive work schedule of 10 hours per day and 6 days per week, necessary to meet the analysis and reporting schedule, was maintained for two to three weeks on occasion without any apparent ill effects on the work output.

As the reporting of the Mercury mission results progressed from flight to flight it became increasingly clear that a strong editorial policy would have to be followed in order to insure that the PLMR's would be effective. One reason why this strong editor policy was necessary was that quite often it was necessary to dicuss different facets of a subject in different sections of the report, with the sections being prepared by different authors; a strong editorial hand was needed in such cases to make sure that the various discussions were consistent with each other and with the facts. Another reason was that the various sections of the report needed to have a reasonable consistency in the format, and amount of summary material and depth of discussion relating to the systems' performance and their effect on the overall mission results; a strong editorial hand was again needed to implement and enforce these requirements.

From experience it was thought that a single person should perform the final editing task; however, as the reports became larger and more complex with the longer flights, it also became apparent that one person could not edit all sections of the report in the short time available. The compromise used in the reports of the last few flights was that one person (the Chairman of the Senior Editorial Committee) edited the technically important sections of the report, and the supporting sections of the report were edited by an editorial assistant or one of the members of the Senior Editorial Committee. This arrangement worked quite satisfactorily, although the work load on the Chairman was very great, particularly during the few days just prior to final typing and printing of the PLMR.

During the period just prior to printing the report, the senior editorial committee reviewed and edited all sections of the report. This review was accomplished to insure that the various sections were compatible in the discussions and treatment of common subject matter. The report was then reviewed in detail by the staff of the Project Managers Office for accuracy and technical emphasis. It was found that the various reviews and editings of the sections of the report and the report as a whole were necessary, although publication of the report was delayed somewhat by this process. Experience showed that the most useful report resulted from a compromise between the conflicting requirements of completeness, clarity, and technical accuracy on the one hand and an early publication date on the other. It was also found that a report was ineffective if it was not complete, clear, and factual.

## Conclusions

As the Mercury Project progressed from the relatively simple flights to the more lengthy orbital missions, the postflight data processing, mission analysis, and reporting, went through a steady evolutionary process. A number of lessons were learned and are summarized as follows:

### Data Processing

(1) Electronic data-processing equipment can accurately process quantities of data that are impossible to accomplish in the same time with manual methods.

(2) Analysis requirements must be determined in advance and data processing must be planned to supply these needs.

### Analysis

(1) Mission-oriented technical supervisors are needed to supervise the analysis in order to insure integration and coordination of the effort.

(2) Extensive time-history data are essential to the analysis of spacecraft system performance.

### Reporting

(1) A report should have all of its technically important sections edited carefully by one person if the report is to be of maximum usefulness.

(2) A report, to be useful, must be a compromise between the conflicting requirements of completeness, clarity, and technical accuracy on the one hand and an early publication date on the other. Such a report is ineffective if it is published quickly but is not complete, clear, and factual.

## References


1. Staffs of NASA, Nat. Inst. Health, and Nat. Acad. Sci.: *Proceedings of a Conference on Results of the First U.S. Manned Suborbital Space Flight.* Supt. Doc., U.S. Government Printing Office (Washington, D.C.), June 6, 1961.
2. Staff of NASA Manned Spacecraft Center: *Results of the Second U.S. Manned Suborbital Space Flight, July 21, 1961,* Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
3. Staff of NASA Manned Spacecraft Center: *Results of the First United States Orbital Space Flight, February 20,1962.* Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
4. Staff of NASA Manned Spacecraft Center: *Results of the Second United States Orbital Space Flight, May 24, 1962.* NASA SP–6, Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
5. Staff of NASA Manned Spacecraft Center: *Results of the Third United States Manned Orbital Space Flight,*

# 14. SPACECRAFT PREFLIGHT PREPARATION

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**Summary**

This paper presents the evolution of test philosophies and procedures used in preflight checkout of Mercury spacecraft at Cape Canaveral, Fla. The impact on preflight operations of tight schedules, mission changes, discrepant performance of ground and spacecraft equipment, and new information gained from ground testing and flight are discussed. Included in this discussion are numerous examples to illustrate the kinds of problems that were encountered and their effects on preflight operations. In addition, this paper presents the lessons learned in preflight preparation and checkout over the 4-year span of the program.

Test operations personnel learned that only formalized testing with all inter-dependent systems operating simultaneously would provide a flight-ready spacecraft. Tests emphasized astronaut safety and included participation of the astronaut as often as possible. Few substitutes for actual flight equipment were permitted during spacecraft assembly, rigging, and testing. Such matters of quality control as cleanliness, component limited-shelf and limited-operational life, and equipment failure, influenced the test philosophy. Validation and troubleshooting of spacecraft systems revealed the need for many more test points to be provided for in-place testing. Repair and bench testing of failed equipment reemphasized that the equipment needed to be made more accessible for removal and reinstallation. Rapid feedback of test results and failure analyses to design and manufacturing personnel was necessary and led to the increase of inspection and on-the-spot failure analysis. Digital checkout equipment was developed and proved that digital computer systems were superior to analog methods in providing information and control to test engineers.

## Introduction

Preflight preparation and checkout experience began at Cape Canaveral in 1959 with the Big Joe boilerplate spacecraft. This spacecraft was the first to be launched in Project Mercury. The Big Joe spacecraft was designed and built by the National Aeronautics and Space Administration (NASA) to determine the aerodynamic and heating characteristics of the Mercury shape.

In the following year, a variety of test and checkout equipment and the first production spacecraft arrived at Cape Canaveral. During the next 2 years, the techniques and procedures for preparation and checkout of spacecraft for manned flight were developed and refined.

By the time of the early manned flights, these preparations and procedures had been proved through operational experience. A formal but flexible operations routine had evolved, incorporating close coordination with design, mission management, manufacturing, and quality control groups. For example, components were inspected and tested before installation; and work to be done on the spacecraft was described in detailed work sheets. This procedure controlled the disturbance of spacecraft components and assured that the status of the spacecraft configuration was known at all times. Detailed test procedures had been written, and step-by-step test results recorded. Checklists had been established to guide spacecraft assembly and configuration before each test.

## Spacecraft Assembly

In preparation for spacecraft testing, component mockups and simulators were constructed and used as substitutes for components that were fragile, dangerous to handle, or in short supply. However, it was found that these mockups and simulators could not be constructed accurately within a reasonable cost and time schedule, and therefore they proved to be of marginal value.

For example, wooden pyrotechnics mockups did not properly establish cable fits, and substitute escape towers did not establish clearances. This resulted in delays and difficult working conditions when modifications had to be made while at the launch pad. Other simulators did not work because of the high packaging density and multiple interfaces inside the Mercury spacecraft.

Ultimately, it was deemed necessary to fit-check all flight items simultaneously, and, where substitutes had to be used, exact flight types were required. Because better facilities for mechanical modifications were available at the point of manufacture, experience indicated that complete assembly of the spacecraft should be accomplished at the factory; this was true even for those components which had to be removed for shipment.

## Test Preparation

### General

In the early planning stages of Project Mercury, it was thought possible to deliver flight-ready spacecraft to Cape Canaveral, conduct a single, total spacecraft test in the hangar, and launch very soon thereafter. However, it was demonstrated that more preflight preparation was required at the launch site and formal procedures evolved from experience.

Before spacecraft testing was begun, very careful preparations were made. Each step had to be formalized through configuration documents, checklists, and test procedures. The ground-support equipment was tested to prove its readiness. Test complexes were checked for compatibility with the particular spacecraft. The spacecraft was put into test position and its configuration conformance to test plans was established; of particular concern were proper cabling and plumbing of all systems. Then the spacecraft was connected to the complex and testing was begun.

Various efforts were made to accelerate preparation of the spacecraft; for example, when the spacecraft was idle, as during periods when data were being analyzed, efforts were made to continue work on the apparently-unaffected systems. However, it was found that this work would adversely affect the test setup and thereby the spacecraft preparation schedule. Mercury components were so closely packed that there was little room for a man to work inside the spacecraft without accidentally damaging such things as cables, tubing, connectors, or cameras. Generally, it was ruled that only test-associated work would be done on a spacecraft while it was being tested.

Early in the program before systems interrelationships had been completely analyzed, some equipment was damaged when tests of one system influenced another. For example, reaction control system (RCS) valves in a dry state overheated when activated by the automatic stabilization and control system (ASCS).

As test crews and planners gained experience in attending to these many details, test plans became more reliable. Offsetting this experience were the number of modifications made to the spacecraft to accommodate mission flexibility and safety and to improve systems performance. As a result, plans and procedures were constantly changing.

### Test Philosophy and Procedure

Gradually, a set of guidelines evolved which were used as the basis for all testing. Two principles served as foundations for checkout procedures throughout this evolution. The safety of the astronaut was considered foremost, and secondly, all philosophy was directed toward a test plan which would guarantee a flightworthy spacecraft at lift-off. These were expanded to six principles which were applied to all spacecraft tests.

*Building block approach to testing.*—The operational status of each system and each component in the system was functionally verified before that system was operated concurrently or in conjunction with another system with which it might have an interface.

*End-to-end testing.*—During testing, the initiating function and end function took place

sequentially as would actually occur in flight. The use of artificial stimuli was minimized. Implementation of this guideline was most evident in the hangar-simulated flight test.

*Isolation and functional verification of all redundancies.*—All redundant signal paths were isolated and functionally proven by end-to-end tests. These included redundancies between the spacecraft and launch vehicle and redundancies within the launch complex.

*Interface testing and verification.*—There were two basic interfaces in Mercury: The spacecraft to launch vehicle and the space vehicle to ground complex. These interfaces included RF, hardwire, and mechanical features. Tests involving these interfaces were consistent with the test philosophy previously discussed, namely, end-to-end testing and testing of all redundancies.

*Mission profile simulation.*—Simulated mission tests, which included the spacecraft, launch vehicle, and ground complex, were designed to approach functionally actual mission conditions as nearly as possible. This procedure included simulating real-time functions through orbit insertion. The astronaut was aboard for these simulations and functioned as he would during the actual flight. These simulated flights were made both in Hangar S and at the launch pad. Figure 14–1 shows preparations being made for a simulated flight test of a spacecraft in the altitude chamber.

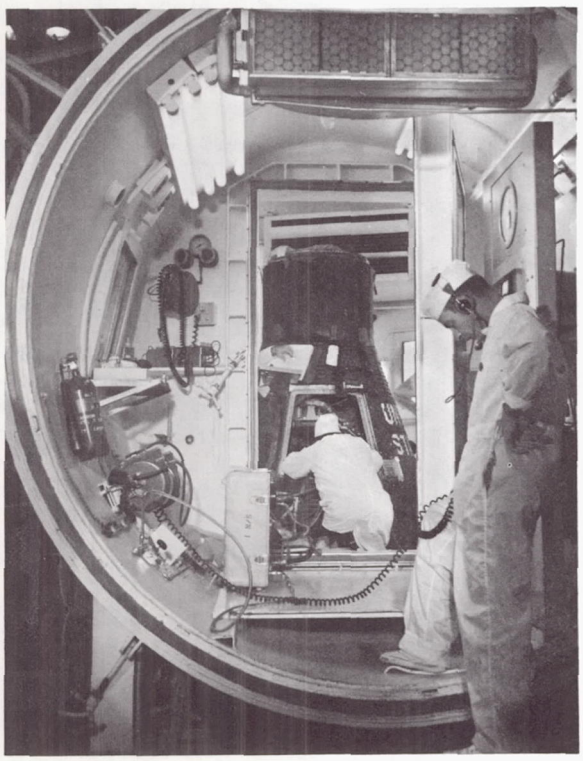


FIGURE 14–1.—Spacecraft being prepared for simulated mission test in altitude chamber at Cape Canaveral.

*The astronaut as an integral part of the system during tests.*—The astronaut was considered part of the total system and functioned during systems test and mission simulations as he would during the actual mission. This resulted in a dual advantage. The system tested was closer to flight configuration when the astronaut was included, and the astronaut became intimately familiar with the spacecraft and spacecraft system. Figure 14–2 is a photograph of a spacecraft on the RF tower for communication tests. This test, with Astronaut L. Gordon Cooper, was made to determine voice clarity under simulated flight conditions.

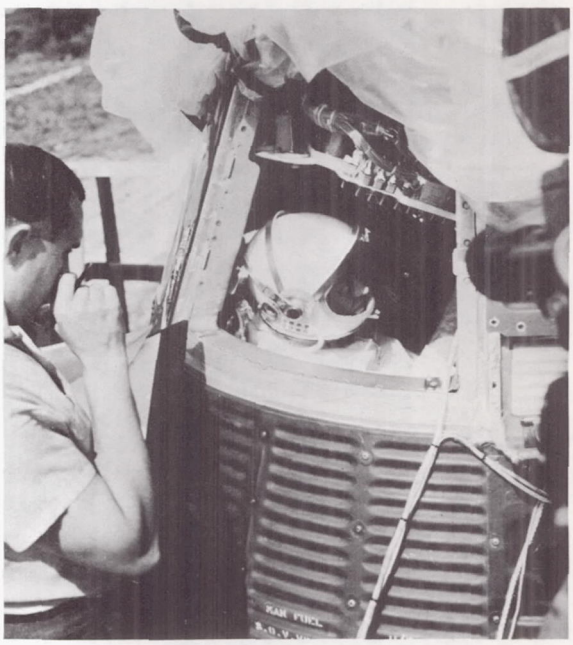


FIGURE 14–2.—Astronaut Cooper in spacecraft on RF tower for communications test.

## Component Acceptability

Components of proven design were planned for use in Project Mercury. In order to insure that only properly-operating items of these proven designs were used for flight, not only spare parts but also many components installed in the spacecraft were subjected to testing at

Cape Canaveral. Numerous component failures were experienced during these spacecraft tests; in addition, during 1962 and 1963 approximately 50 percent of component spares were rejected after testing. These failures were discovered by rigorous preinstallation acceptance (PIA) tests which in most cases exceeded the test conditions that could be achieved after component installation. These tests increased confidence that replacement components in a state of incipient failure would not be installed in Mercury spacecraft.

Control of the stock of spares also was tightened to assure that qualified replacements were available when troubles occurred. Spares which were significantly affected by shelf life were periodically tested and returned to stock. In special cases, the inspection was extended to the source. Vendor and component manufacturing plants were visited by engineers and inspectors to convey the nature of problems and to encourage higher quality of work.

Component acceptability and rejection rate was governed by such factors as performance criteria modification, the delivery of partially qualified items, and inadequate shelf life of some components.

#### Modified Performance Criteria

During systems tests of Mercury spacecraft, the effects of electrical-current surges demonstrated the need for performance criteria modification. These current surges, resulting in momentary variation (transients) of the battery voltage, occurred during testing and were attributed to the normal starting of mechanical-electrical systems, such as the orbital timing device or the spacecraft cameras. As a result of these voltage transients, energized timers would occasionally exhibit early time-out, interference would appear in instrumentation amplifier outputs causing faulty indications, and noise would appear in the astronaut voice channels. The solution to these problems required inclusion of a special battery for the maximum altitude sensor, the addition of capacitors to circuits with time relays as a protective measure to prevent early time-out, and the replacement of components with like items that demonstrated low susceptibility to voltage transients.

Extensive voltage-transient tests were added to spacecraft checkout procedures to prove equipment immunity to these effects. These procedures were frequently quite involved.

High voltage problems were encountered in ground power supplies. Electrically-regulated power supplies operating over long lines tended to react and surge to high voltages and cause loss of remote sensing, and they were abandoned in favor of lead-acid batteries.

#### Partially Qualified Equipment

Equipment not fully qualified for flight when delivered included tape recorders, ECG amplifiers, water traps for the environmental control system (ECS), and impedance pneumographs.

Tape recorders were brought to acceptable status by careful shop asembly and testing. The electrocardiogram (ECG) amplifiers were redesigned and rebuilt. Internal voltage regulators and feedback loops were modified. Rebuilt units were requalified in detail. Later, new models were specified for vendor development based on experience with the originals.

In some cases, flight systems had to be modified to accept new components, and special systems tests had to be devised to be sure that the effects of the modification were not serious. For example, the environmental control system performance depended upon closely balanced pressures and flow, and testing of the system was conducted to insure that the addition of the water trap did not degrade system performance in the MA–9 spacecraft.

#### Shelf Life

Many components procured for the Mercury Project proved to have inadequate shelf life because of the time period required to complete the program. Such items as rockets had to be refurbished because of an 18-month shelf limit established by the vendors. A system was established whereby equipment that utilized rubber O-rings was periodically exercised or returned to the vendor for replacement of time-critical components. For example, the Environmental Control System (ECS) negative-pressure relief valves were operated at prescribed time intervals, and the Reaction Control System (RCS) relief valves were reconditioned by the manufacturer.

Another problem involved deterioration of the solder connections of nichrome bridge wires

to the electrical connectors of many pyrotechnic initiators. This deterioration resulted in a gradual increase in the resistance of squib circuits. This was precluded by establishing a time limitation of 6 months between date of soldering and actual use.

#### Test Equipment and Procedure Changes

The need to prove the acceptability of spacecraft equipment required many changes in procedures and test equipment at the Cape. Component and systems simulators were used less and less in spacecraft testing even to the point of requiring participation of the astronaut, fully suited.

Bench simulators were made more realistic. Voltage-transient generators and ECG simulators were added to the Cape's test equipment. Battery source impedance and load impedances were more carefully simulated as was line noise character. There was, also, an increased tendency to operate equipment on the bench in exact connection with production models of their companion components and systems. Camera solenoids and transmitters were properly connected to and operated with instrument systems during final bench tests before spacecraft installation.

### Quality Assurance

Some equipment and components such as rockets and pyrotechnics could not be fully validated before use. Reliability of these items was almost entirely dependent upon good design, workmanship, and qualification. This workmanship requires great patience and attention to detail even under the tedium of production lines. Considerable progress has been made in promoting this extreme attention to detail which directly contributes to the success or failure of each spaceflight mission and the safe return of the astronaut.

In the MA–9 mission, the three retropackage umbilicals and one of the two spacecraft-to-adapter umbilicals failed to separate from the spacecraft. Each of these contained two squibs. and initiation of either squib should have resulted in explosive disconnection. Postflight analysis revealed that the umbilicals failed to separate from the spacecraft because the squibs were not loaded with the appropriate charge.

As the Mercury Project matured, it became evident that the use of proven and qualified components did not result in the reliabilities desired to satisfy man-rated system requirements. A more-rigid quality control procedure was required in all aspects of component and system assembly. The need for this requirement was typified by the number of discrepancies (performance or configuration deficiencies) to be corrected for the MA–9 backup spacecraft. A total of 720 system or component discrepancies were recorded, of which 526 were directly attributed to a lack of satisfactory quality of workmanship. Of this number, 444 required specially-scheduled time to correct.

Additionally, flight-safety considerations required that inspection be made of all parts and components scheduled for the space-flight program. These inspection requirements extended from the parts vendor to the Cape in order to locate and reject every defective or marginal part.

As a result of inspection, fourteen 1,500 watt/hour storage batteries were rejected for case leakage during preparation for the MA–8 mission. Several incidents of leakage were due to tooling holes not being plugged during manufacture. Others were from case cracks or undetermined sources. Also, an inspection of battery vent-pressure relief valves revealed dimensional deviations in valves after assembly, and improperly applied potting adhesive. Three of these valves failed to operate at proper pressures. These defective batteries were rejected following inspection at the Cape.

Five failures were experienced on gas-pressure regulator assemblies in the MA–8 reaction control system (RCS). An investigation of the failed assemblies revealed that internal scratches, inadequate cleanliness, and improper torquing of end caps were contributing causes of these failures.

Also in the RCS, an examination of failed gas-pressure vent valves revealed damaged O-rings. In one case an O-ring was found to be scuffed, while in another case the O-ring had a metal fragment driven into the material.

The MA–8 spacecraft was demated from its launch vehicle and returned to Hangar "S" to replace the manual selector valve in the RCS due to a leakage encountered during a preflight pressure check of the system. Upon removing the valve, it was noted that the valve had been

installed out of alinement so that an excessive side-load was induced into the valve internal parts.

During an inspection of the escape-tower wiring for the MA–6 primary and backup spacecrafts, it was found that the electrical connectors had improperly-soldered joints. Additionally, it was discovered that improper insertion of the conductor wire into the solder had been made as a result of the use of an 18-gauge wire with a 20-gauge solder pot.

In Project Mercury, thousands of man-hours were expended in testing, calibration, assembly, and installation of a variety of hardware that later failed to meet performance specifications or that malfunctioned during systems tests in a simulated space environment. When malfunctions occurred or when these components failed to meet specifications, it was necessary to remove, repair, or replace them, a procedure which could have been avoided in a large percentage of cases if adequate attention to detail during manufacture or thorough inspection before delivery had been exercised.

### Component Accessibility

Mercury spacecraft were literally packed with equipment and components were installed three deep in some instances. Limited interior working space, which posed a severe handicap to preflight preparation, resulted in a certain amount of wiring and equipment damage during normal work and test operations. Repair was a continuing work item during all phases of spacecraft modification and checkout. Any system affected by these repairs or modifications had to be reverified by test.

Extensive changes and modification were caused primarily by component or subsystem malfunction, as well as extension of mission requirements.

As an example, it became necessary to replace MA–6's life-limited carbon dioxide absorber in the ECS, since more time than had been planned was required to check out the system. This replacement required no less than eight major equipment removals and four revalidations of unrelated subsystems. It caused an overall delay of nearly 12 hours. By way of comparison, it took only an hour and a half to replace the carbon dioxide absorber itself. Ten and one-half hours were used to gain access to the absorber and then to restore the spacecraft to its original condition.

The number of removals of equipment is an index of the amount of modification, repair, and servicing required as the program progressed. Figure 14–3 exemplifies the amount of work required at Cape Canaveral.

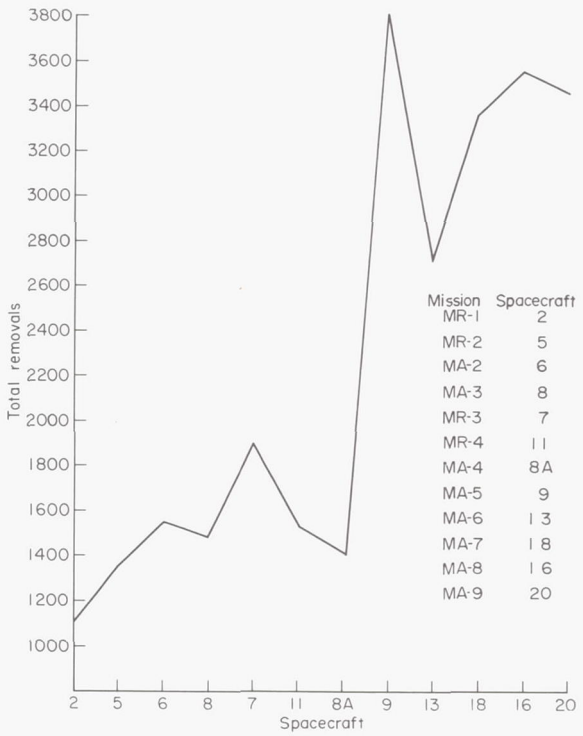



FIGURE 14–3.—History of equipment removals for Mercury spacecraft for rework service and replacement.

### Cleanliness

Early in the Mercury program motion pictures of the inside of a spacecraft in orbit showed washers, wire cuttings, bolts, and alligator clips floating in the cabin. The cabin fan became plugged on an early unmanned flight with similar free-floating debris.

Such evidence led to more care in the habits of technicians working inside the spacecraft. A periodic tumbling of the spacecraft to dislodge and expose dirt and loose objects became standard practice at the Cape. Figure 14–4 shows a spacecraft in the tumbling fixture during a cleaning operation, and figure 14–5 shows the debris removed.

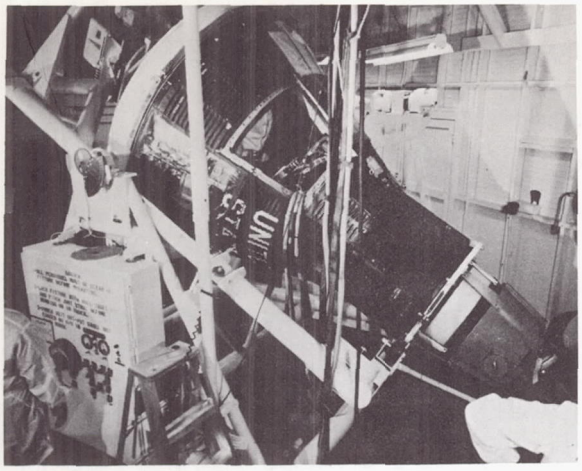


FIGURE 14–4.—Spacecraft being tumbled to remove debris left during work periods.

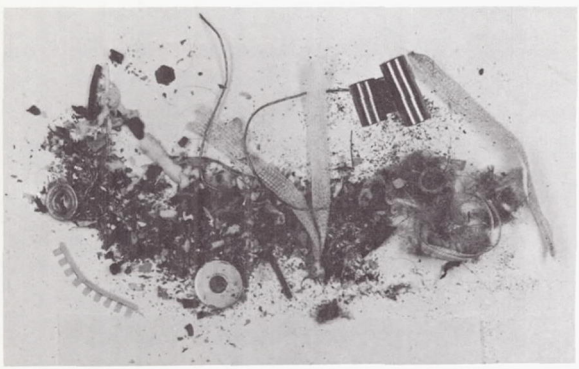


FIGURE 14–5.—Debris removed from spacecraft during tumbling.

Technicians generally were not aware of the strict cleanliness required in handling components of the ECS and RCS systems. It became necessary to specify handling procedures for these highly dirt-sensitive components. Many parts were kept in sealed plastic bags until installation was to begin, at which time ultra-clean handling methods were used. Vendors have delivered many items of spacecraft equipment which contained wire ends, solder balls, and stray hardware. Such items as gums, powders, lubricants, chips, and hydrocarbons have appeared on components where they could not be tolerated for proper operation. Hydrogen peroxide systems have yielded some decomposables which could have caused extreme reaction. Breathing oxygen and drinking water also have been contaminated. As a result, all consumables were chemically analyzed before being put into their spacecraft containers, and a variety of equipment which was found to contain contaminating deposits was carefully inspected and cleaned before being used. This equipment included astronaut suits, valves, hoses, and tubing.

## Provisions and Procedures for Troubleshooting

It can be seen from the preceding discussion that there was a great need for troubleshooting spacecraft components both in spacecraft and on the bench. As a consequence, facilities at the Cape were expanded to include a malfunction investigation laboratory, staffed with experienced specialists in such areas as X-ray, spectroscopy, microscopy, and chemistry. Also, because of the need to qualify many spacecraft components, a laboratory of test equipment was developed and fully equipped with environmental chambers, shaker table, accelerator, impact tester, and pressure testing equipment.

### Absence of Test Points

In Project Mercury, it was necessary to add ground support equipment to that provided with the spacecraft and to devise means for testing individual components in the spacecraft. Test points were not available and interconnecting cables and tubing had to be broken into for tests. This invalidated the very circuit or pressure system that was being tested.

### Preplanned Troubleshooting

In Project Mercury it became necessary to plan exact steps and equipment configuration before troubleshooting was begun. Expected values in response to stimuli that had been carefully defined were listed in documents prepared in advance. It was found that preplanned troubleshooting procedures significantly reduced testing time.

In addition to drawings and standard spacecraft test procedure, the contractor provided logic diagrams and detailed drawings and specifications of systems and components. Systems consisting of many separate circuit elements were detailed by separate subsystem diagrams showing all wire routing throughout the spacecraft. As an example, instrument systems were broken down to show each sensor and



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its signal conditioning and cable connections. This was in addition to overall system cabling diagrams and detailed drawings of repairable items including mounting details that were provided. These drawings were invaluable for troubleshooting.

## Scheduling

To accomplish spacecraft preflight preparations and checkout within schedule objectives, it was necessary to increase the number of spacecraft undergoing preflight preparations at Cape Canaveral from one to two, or three, at any given time. This approach provided additional time for preflight preparations of each spacecraft without a corresponding increase in the time interval between successive missions.

### Preflight Preparation

Preflight preparations and checkout operations included: (1) modifications to update the untested spacecraft configuration based upon knowledge gained from previous flight experience; (2) modifications as extensive as reworking a spacecraft from a suborbital configuration to an orbital configuration to increase spacecraft systems capabilities for extended mission requirements; and (3) changes and modifications resulting from component or system malfunctions during preflight testing.

Changes of considerable magnitude were made at the Cape only because it was more efficient and less time consuming than returning the spacecraft to the factory. In any event the final flight configuration of any particular spacecraft could not be entirely determined until successful completion of the preceding mission. This required that final configuration changes be accomplished at the Cape if the schedule was to be maintained.

On the average, spacecraft modifications accounted for more than half the time that the spacecraft remained at the Cape prior to flight. Examination of the average time that the spacecraft spent at Cape Canaveral shows that 60

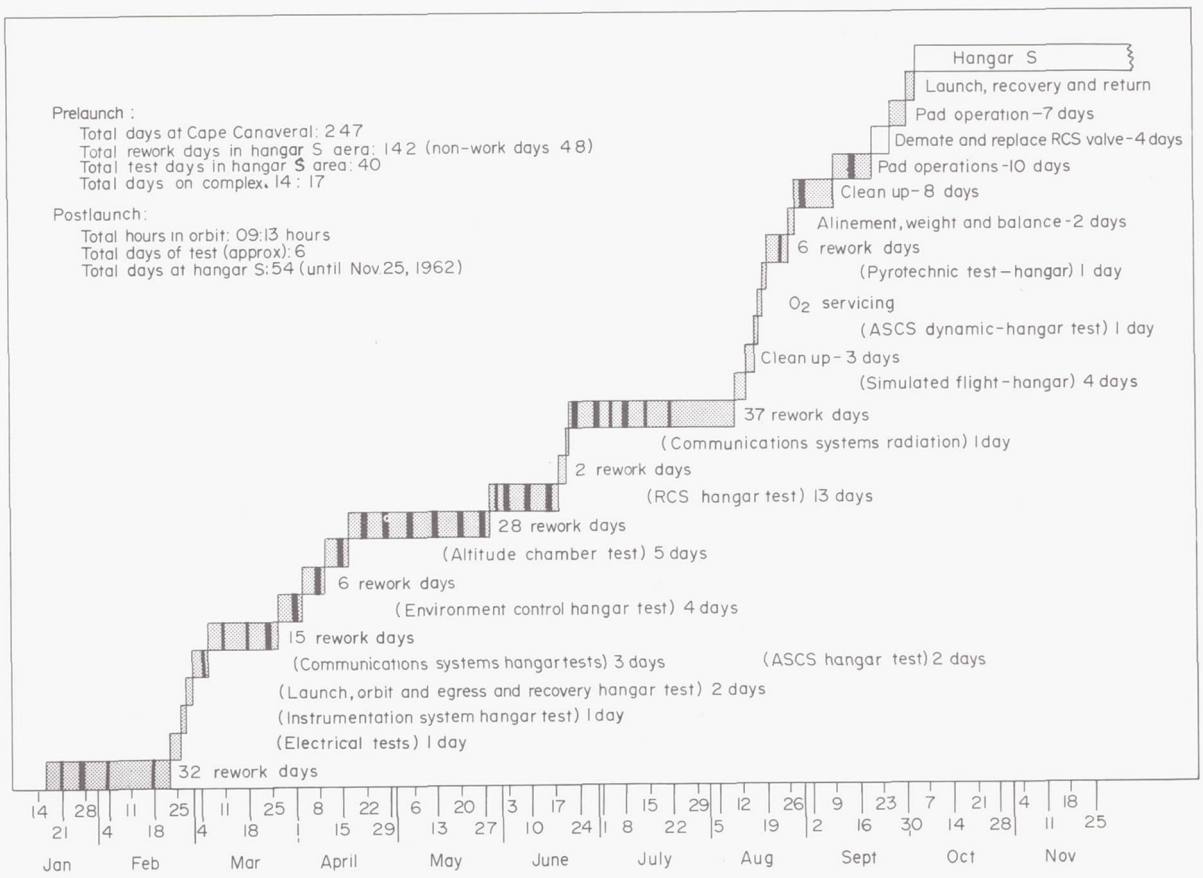



FIGURE 14–6.—Test and work schedule for prelaunch preparation of spacecraft in Hangar S.

percent of the total time involved modification, repair, assembly, service, and inspection. Only 25 percent of the time was spent in hangar tests and 15 percent for all work and testing at the pad.

When converted to months, these percentages show approximately 3 months for hangar work, 1⅓ months for actual hangar testing, and 1 month on the launch pad, for a total average time at the Cape of approximately 5⅓ months.

The Mercury-Atlas spacecraft averaged 33 more hangar work days, 6 additional hangar test days, and 4 additional days on the pad than the Mercury-Redstone spacecraft. This small increase in test and pad time indicated that the increased complexity of Mercury–Atlas missions was offset by increased experience, and therefore there was little effect on time required for hangar testing or total pad time. Figure 14–6 shows how the time was divided between testing and other work in the preparation of spacecraft 16 (MA–8).

#### Operational Life

Equipment having a short operational life caused many problems in meeting spacecraft checkout schedules. Dissipating chemicals, such as lithium hydroxide which was used to adsorb carbon dioxide in the astronaut's breathing-oxygen circuit, exemplify this problem. The carbon dioxide and oxygen partial-pressure sensors are another example. The latter had to be installed late in the countdown and required some spacecraft disassembly for installation. If holds occurred during the countdown, a new removal-activation-calibration-installation cycle had to be completed.

Spacecraft cameras also posed short-life problems in the Mercury Project. Most of the camera shutter and film advance mechanisms failed frequently. Complicating matters further was the fact that the camera solenoids caused momentary deep reductions in battery voltage because of periodic pulsing. In addition, excessive back-voltages in the coils caused failures of programer switches. Because cameras placed transients on other systems, these systems had to be tested often to establish their ability to accept these transients. This extended use, in turn, burdened the cameras and their failures accelerated. Spare cameras soon became unavailable.

#### Failure Analysis

Rapid failure detection and corrective action were basic requirements in maintaining program schedules. Facilities were provided to permit extensive failure analyses at Cape Canaveral where failure conditions were intimately known to engineers and technicians. These analyses provided a basis for accurate feedback through quality control channels. However, the lack of spares often made it impossible to take the necessary action required in order to meet preflight preparation and test schedules.

### Evolution of Digital Checkout Equipment

One of the more time consuming problems during Project Mercury was that of spacecraft preparation for testing. This required connecting a large number of cables to the installed equipment, largely by breaking cables and tubing. As shown in figure 14–7, many of

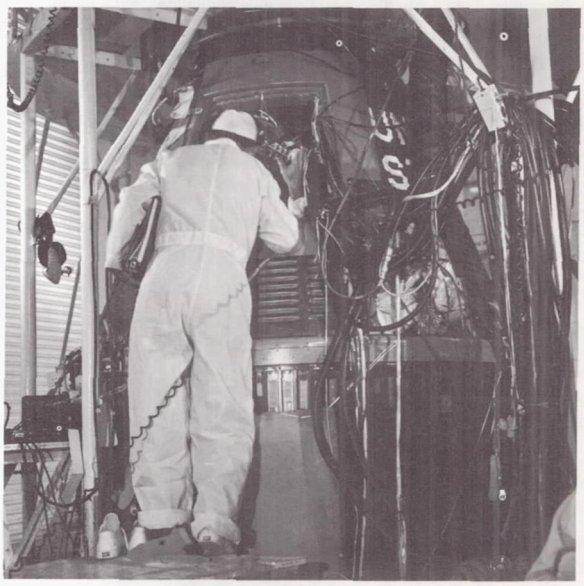


FIGURE 14–7.—Spacecraft in Hangar S.

these cables were draped around the spacecraft and through the hatch. Not only did this tend to invalidate systems being tested, but it required much detailed planning and preparation of the spacecraft and test equipment. Each time the spacecraft was moved, the entire test complex had to be torn down, putting another strain on equipment in the spacecraft.

A study of digital equipment proved that data conversion provisions could be built into

the spacecraft and permanently wired to test points. Pulse code modulation—a form of digital data—allows compression of data so that hundreds of measurements can be sent over one cable. By this means, test configuration problems can be greatly reduced. Spacecraft can be moved from place to place with much less breakdown and buildup of test configurations.

As the Mercury Project progressed, many different methods of data presentation and distribution were investigated. Through these efforts, it was demonstrated that data of the pulse form could be consistently transmitted by radio frequency or by cable. The receiving and conversion equipment which was used for about 4 years proved to be a reliable and accurate means for presenting data to test engineers.

In an effort to make data more immediately useful to these engineers, printers and digital displays were added. It was gradually realized that this immediacy was of prime importance to men who had to make constant decisions as to the state of their systems. These studies of improvements needed in spacecraft checkout led to the design of a digital computer-controlled system capable of automatic checkout of manned spacecraft. It also had the capability of use as a completely manual system controlled by test engineers miles from the spacecraft, thereby allowing a natural evolution to automatic checkout. An experimental model was assembled and proved during hangar and pad tests of Astronaut Cooper's spacecraft.

### Technical, Configuration, and Mission Reviews

Close coordination between preflight operations personnel and those of other organizations, including contractors, subcontractors, vendors, the Department of Defense, the ground complex, the network, and other NASA centers was maintained continuously to insure that interface compatibility of operations planning as well as equipment left no significant problems unresolved.

Throughout Project Mercury, a continuing series of technical, configuration, and mission review meetings were conducted to resolve problems, to initiate action where necessary, to coordinate activities on a wide variety of matters affecting each Mercury mission and to provide technical direction where required. In addition, engineering specialists from these organizations met frequently at Development Engineering Inspections (DEI) at the spacecraft manufacturing plant to review in detail the hardware being produced so that results of current experience were reflected in this hardware. Each of these efforts provided management a valuable tool for directing effort along the desired channels. A significant management device employed during the project to assure mission success was the spacecraft Flight Safety Review meeting held prior to each launch. At this meeting, every activity connected with the spacecraft was discussed in detail between management and engineering specialists to determine the flight readiness of the spacecraft. The criteria established for this review was that a Mercury launch would not take place in the face of unresolved difficulties that might affect mission success or flight safety.

### Conclusions

The foregoing discussion has presented in detail the lessons learned in preflight preparation and testing during the Mercury Project. The conclusions that have been drawn from this experience follow:

(1) Test procedures incorporating the techniques of end-to-end testing, interface verification, and astronaut participation should be documented and continually updated.

(2) Spacecraft should be completely assembled at the factory, using a minimum of simulated hardware.

(3) The number of component malfunctions during testing proved the need for better quality control and inspection procedures.

(4) The lack of test points, spares, and formalized troubleshooting procedures often hindered rapid malfunction analysis and corrective action.

(5) Limited shelf life and operational life of components create spares problems and possible delays in launch schedules.

(6) Pursuance of exacting cleanliness procedures reduces the possibility of component and system malfunctions.

(7) An automatic checkout system can provide complete real-time test documentation and better control of test operations by test engineers than an analog system.

# 15. FLIGHT CONTROL OPERATIONS

By JOHN D. HODGE, *Asst. Chief for Flight Control, Flight Operations Division, NASA Manned Spacecraft Center; and* DANIEL T. LOCKARD, *Flight Operations, NASA Manned Spacecraft Center*

**Summary**

An organization was established at the beginning of Project Mercury to provide support to the astronaut in all phases of the mission. This organization was to monitor and direct the mission to insure a greater margin of safety for the astronaut, provide support necessary for mission success by extending the analysis capability of the astronaut, and record data for detailed postflight analysis.

To be able to accomplish the assigned tasks, it was necessary to plan operational requirements, generate documentation for real-time use, and train personnel specifically for the job of flight control.

As the program progressed from the planning stages through manned orbital flight, flight control progressed in its ability to provide better support.

All Mercury flights were successfully supported by flight controllers at the Mercury Control Center and sites located throughout the world. During the program a number of difficulties occurred which required changes and improvements to methods used in the early flights. Most of these difficulties were corrected and flight control provided the necessary support to contribute significantly to the success of the program. Because of the experience gained in the Mercury program the flight control organization is now more qualified to progress to the more complex programs planned for the future.

## Purpose of Flight Control

At the beginning of the Mercury program, it was recognized that a ground-based crew would be needed to aid the astronaut in monitoring the spececraft systems, to evaluate systems performance, and to advise the astronaut on the proper action necessary in case of a spacecraft malfunction. Also, the ground crew would have the capability to command reentry of the spacecraft in unmanned vehicles and in manned vehicles should the necessity arise. In addition, it was necesary that the flight control organization record information for postflight analysis. The major objectives of flight control were:

(1) Assist the astronaut during critical mission phases where additional close monitoring and direction would insure a greater margin of safety.

(2) Provide support as required in conducting the flight plan to contribute to mission success.

(3) Extend the system analysis capability of the crew and make available experts in all vehicle systems should they be needed to support the crew.

Flight control is the team work existing between the spacecraft crew and a worldwide ground crew to accomplish manned space flight. This task covers the entire premission preparation phase and terminates with the recovery of the spacecraft and crew. Flight control was broken into five separate tasks:

(1) Preparation of the ground and flight crews prior to launch, which includes the detailed development of Flight Plans, countdowns, Mission Rules, and training of personnel in vehicle systems and ground network operations.

(2) Execution of mission control, which includes the direct supervision and coordination of all aspects of mission real-time ground support and the control of the launch vehicle and spacecraft crew during flight.

(3) Supplement the vehicle systems analysis capability of the spacecraft crew, primarily by the compilation, reduction, and evaluation of telemetered and voice data from the spacecraft and its crew.

(4) Assistance to the spacecraft crew in attaining the mission objectives. This task requires participation in the development of an optimum flight program, provision and coordination for real-time ground support necessary for execution of this optimum Flight Plan, modification of the Flight Plan in real time as required, and assistance in preparation for subsequent mission phases.

(5) Participation in postmission analysis, recommendations, and the preparation for subsequent flight programs.

## History of Communication Between Ground and Pilot

The development of a complex vehicle requires the parallel development of a test and control organization to provide the support necessary to accomplish the test objectives.

The advent of air-ground data links has allowed a ground-based crew to monitor the test in progress, to modify the flight if necessary, and to recommend the most expeditious course of action to be taken in the event of a contingency situation. The missile age brought about the development of a ground-to-air data link by which information and commands could be sent from a monitoring ground crew to the vehicle to modify its flight plan.

In the early planning stage of Project Mercury, it became evident that an extensive tracking and data-acquisition network would be required. The presence of man in an orbiting satellite demanded that considerably different requirements be placed on the tracking network than had previously been necessary for unmanned vehicles. The most significant of these requirements was that it was now imperative that the network respond rapidly to contingency situations to insure adequate safety of the astronaut. In order to meet the new requirements and to analyze the progress of the flight, the tracking network combined previously used methods of monitoring. These methods are telemetry and radar and voice communications which are discussed as follows:

(1) Telemetry and radar, which were used to monitor and track satellite and missile systems, provided a means in Project Mercury not only of analyzing launch vehicle performance and trajectory progress but also of monitoring spacecraft systems and making medical analyses of the astronaut's physical status.

(2) The voice conversations between the astronaut and the spacecraft communicators around the world proved to be invaluable. The ability of the astronaut to make observations and relay them to the control center, to verify telemetry data, to update the retrofire timer, to exchange information with the ground, and to carry on discussion of problem areas proved to be the best tool for flight-control analysis. Voice communications also proved to be a primary method of making a medical analysis of the astronaut's physical status.

## Development of Flight-Control Operations

### Network Requirements

In the planning stages for manned flights, the design criteria for the tracking network were established. These requirements were:

(1) A central control facility able to coordinate a worldwide network of tracking stations.

(2) Continuous monitoring of the powered-flight phase of the mission.

(3) A worldwide network capable of monitoring a spacecraft while in orbit.

(4) Voice, telemetry, radar tracking, and command capability at the time of retrofire for a planned reentry.

(5) A recovery force capable of astronaut rescue in case of an emergency as well as recovery after a normal reentry.

### Development of Detailed Flight Control Operational Planning

As preparation began for manned space flight, it became apparent that a need existed for a well-trained control organization in order to perform the flight-control tasks previously mentioned. As in the case with any engineering or scientific undertaking, the ability to control a mission successfully is primarily a result of premission planning.

*Documentation.*—At the beginning of the project, the different organizations connected with the Mercury program published a number of documents in which the method that should be used to accomplish the flight-control task was described in detail. Some of the documents were revised and used in Astronaut Cooper's

flight. However, the majority of the documents proved to be too cumbersome for real-time use and too difficult to keep updated for use by the flight-control organization. Consequently, some of these documents were revised, others were discontinued, and new ones which would be more adaptable to use in real time were written. As a result of the experience gained by the use of these documents, several specifically designed for flight control were published.

The most difficult task of flight control is that of being prepared to make a real-time decision. A real-time decision by flight control could result in an action to change the entire mission. The action based on this decision may range from a slight variation of the flight plan to immediate termination of the mission. The documentation to be used by flight control personnel not only must have all necessary information available to research a problem, but also must contain information that can be quickly located, if time is limited. The most significant documents that evolved through experience and use were Mission Rules, Flight Plan, Flight Controller Handbook–1, and the Trajectory Working Paper.

*Mission Rules:* A fundamental approach to the analysis of systems failures in any flight-test program is to formulate a set of probable component failures and their respective countermeasures which may either rectify the problem, provide for the safety of the occupant, or protect the equipment. This compilation of preplanned actions for each flight is called Mission Rules. In no other document are the actions of the crew and the flight control teams so well defined. Each rule is carefully scrutinized by the flight controllers and astronauts for possible ramifications which need more clarification. This document shows the integrated actions of the spacecraft crew and ground-support personnel which are required to establish an efficient team that may be called on to take life-saving actions should an emergency situation arise.

These Mission Rules are put to the final test during the extensive series of simulations prior to the mission. Some of the rules may be modified as a result of the realistic situations created by the simulation. A Mission Rule Review is held the day before launch to assure a consistent interpretation and a complete understanding of the rules. A page from the Mission Rules for orbital reentry is shown in table 15–I.

*Flight Plan:* The Flight Plan for the manned Mercury missions consisted of a time-referenced step-by-step list of the astronaut's activities during an individual mission and the necessary supporting information. It was basically written as a guide for the astronaut in conducting the mission, but it also served as a focal point for the coordination of all the inputs into the mission and the coordination of the ground-controller activities with those of the astronaut. In addition, it served as a basis for premission training, simulations, system tests, and detailed management in meeting the mission objectives.

The formulation of the Flight Plan required the coordination of inputs from many organizations into a sequence that not only met the mission objectives and ground rules, but also could readily be performed by the astronaut. The inputs into the Flight Plan were concerned with the astronauts, the spacecraft systems, flight controllers, medical requirements, and experimental considerations. As these inputs were received, they were arranged to meet the requirements of astronaut usage, reliability, priority, Mission Rules, and ground control. In order to obtain the maximum amount of useful information from the flight, the Flight Plan was continuously coordinated with and reviewed by the various input organizations and finally approved by the Operations Director.

The Flight Plan, as an operational document, served several purposes. Primarily, it provided the astronaut with a coordinated schedule of his activities during the mission. It also outlined part of the astronaut's preflight training. The Flight Plan further served to inform the flight controllers of the astronaut's planned activities and was used as a tool to help coordinate the activities. In addition to the activity schedule, the Flight Plan provided the normal and emergency procedures and checklists for the control of the spacecraft and procedures for conducting experimental and medical activities. During the mission it provided a basis from which changes could be made because of system malfunctions or alterations in the requirements. Also, it provided nonoperational organizations with information concerning the activities scheduled for an individual mission. See table 15–II for sample page from flight plan.

*Table 15–I.—Mission Rules—Orbital Reentry*

| Revision | Item Condition—Malfunction | Ruling | Notes, Comments, Standard Operation Procedures |
|---|---|---|---|
| | 8. Failure of one suit fan. | 8. Continue mission. | |
| | 9. Failure of both suit fans. | 9. Select EMER $O_2$ rate ASAP and reenter at next planned landing area. | |
| 2 | 10. Smoke, fumes, unusual or annoying odors in suit circuit. | 10. Switch suit fans. If this does not clear up the fumes or smoke, go to EMER $O_2$ rate and try further to isolate cause. If cannot isolate, reenter next planned landing area. | 10. Check suit $PCO_2$ reading. |
| | 11. Smoke, fumes, fire, unusual or annoying odors in cabin. | 11. Close faceplate, attempt to isolate cause. If source isolated and no other Mission Rules are violated, continue mission. If fire, decompress. | |
| | 12. Faceplate will not reseal.<br>a. Cabin pressure above 4.6 psi.<br>b. Cabin pressure below 4.6 psi. | 12a. Reenter next planned landing area.<br>b. May require contingency landing area reentry or ASAP reentry if cabin pressure below 4.0 psi. | 12. Astronaut should get spacecraft in RETRO ATTITUDE and prepare to reenter. |
| | 13. Conditions for selection of EMER $O_2$ rate. | 13. Astronaut should select EMER $O_2$ rate when:<br>a. Suit pressure below 4.0 psi.<br>b. Respiration rate increasing to 40 breaths/min.<br>c. Unsatisfactory operation of suit heat exchanger that is not corrected.<br>d. Rise in partial $CO_2$ reading to 7.5 mm Mercury.<br>e. Smoke, fumes, unusual or annoying odors in suit circuit. | |

*Table 15–II.—Excerpt From Flight Plan*

| Orbit | AOS | Site mode | LOS | Action | Remarks |
|---|---|---|---|---|---|
| 21 | 32:05 | ASCS<br>Orbit | | A—Turn ON cabin fan and cabin coolant flow for precooling prior to reentry. | |
| 21 | 32:15 | ASCS<br>Orbit | 32:20 | A—Radiation experiment ON for 5 minute period. | |
| 21 | 32:22 | ASCS<br>Orbit | | A—Tape recorder—PROGRAM. Take horizon definition photographs. | |
| 21 | 32:23 | CSQ<br>ASCS<br>Orbit | 32:30 | A—TV ON for pass.<br>Oral temperature.<br>Blood pressure. | The astronaut cannot talk for a period of 3–5 minutes during oral temperature taking. |
| 21 | 32:40 | HAW<br>ASCS<br>Orbit | 32:46 | | |
| 22 | 33:33 | ZZB<br>ASCS<br>Orbit | 33:39 | A—Tape recorder—CONTINUOUS. Complete stowage and preretrosequence checklists. Check manual proportional and FBW-high thrusters if required. Readout fuel and $0_2$ quantities. | |
| 22 | 33:57 | CSQ<br>ASCS<br>Orbit | 34:03 | A—TV ON for pass.<br>C and S-band radar beacons.<br>CONTINUOUS. Report checklists—COMPLETED.<br>CSQ—Confirm astronaut ready for retrosequence. Confirm retrosequence time setting.<br>A—Squib switch ARM at retrosequence minus 5 seconds. | |

*Flight Controllers Handbook:* The first document designed specifically for flight controllers was published in December 1960. This book was designed to contain operational information needed by a flight control team to analyze spacecraft systems problems. Schematics, logic diagrams, and other publications were used to prepare schematics oriented for operational utilization. This document, entitled Flight Controllers Handbook No. 1 (FCH–1), was used from the MA–3 mission until the end of the Mercury Project. During this time, the FCH–1 was modified and revised to include more system details. The final document contained highly detailed functional schematics of spacecraft systems, yet the arrangement of these schematics along with notes explaining details provided information very adaptable to real-time use. The schematic diagram, shown in figure 15–1, was taken from the Flight Controller's Handbook.

*Trajectory Working Papers:* Real-time decisions concerning flight dynamics are of paramount importance to the astronaut's safety and to mission success. Should the flight trajectory vary from the precalculated nominal during launch, there is no time for analysis, and corrective action must be immediate. In order to aid the flight controllers in making these fast decisions, a flight dynamics document was prepared to provide a ready reference of charts, curves, tables, and other data illustrating the expected normal trajectories, calculated allowable limits, and timed sequence of events. This document contained not only information pertaining to all the conditions necessary for insertion of the spacecraft into orbit, but it also contained curves for calculating retrofire times and making reentry landing predictions. Table 15–III and figure 15–2 are examples of information contained in the Trajectory Working Paper.

*Training.*—In November 1960, training courses were organized for NASA personnel who were to become flight controllers. The classes covered basic spacecraft systems. Because of the limited number of personnel available to man a worldwide tracking network, it was necessary to borrow personnel from other organizations to be used as flight controllers on a part-time basis. However, it was soon discovered that this arrangement was not adequate. Since these people were responsible to their own organizations except during a mission, they were not available for premission planning and postmission analysis. In addition, the flight-control tasks interfered with their responsibilities to their own organizations. As a result, it was determined that full-time flight controllers were needed. The first full-time team of systems monitors came to NASA in January 1961, and new techniques of instruction were incorporated through the experience gained in the preceding class. These systems monitors learned the spacecraft and ground systems and conducted the succeeding flight-controller training classes. The following facilities and aids were used in the flight-controller training program: classroom lectures, Mercury procedures trainer, and training documentation.

An updated formal training course was held in April 1962 and consisted of 156 hours of classroom lectures on spacecraft and ground systems. The original NASA flight controllers were the instructors and were responsible for the training lesson plans. The FCH–1 manual was the primary source of information for the lectures on spacecraft systems. Within one year, a total of six classes were conducted without any significant changes in the format.

The Mercury procedures trainer was utilized in training flight controllers in network operational procedures, spacecraft communications, and systems analysis. The first Mercury procedures trainer was installed at Langley Air Force Base, Va., in 1960 and became operational the latter part of the year. The remote site console simulator was also installed at Langley. For a description of the procedures trainer and the simulator, see paper 10. This remote-site simulator was designed to operate from outputs of the spacecraft procedures trainer for simultaneous site-vehicle training. Initially, the procedures trainer was used primarily by the astronauts for systems training, and there was limited availability for use by the flight controllers. In 1961 a Mercury procedures trainer was installed at Cape Canaveral, and more time was then available for the Flight Controllers to train on the one at Langley. The trainer configuration was continuously updated to make it identical with the spacecraft used for the real-time operation.

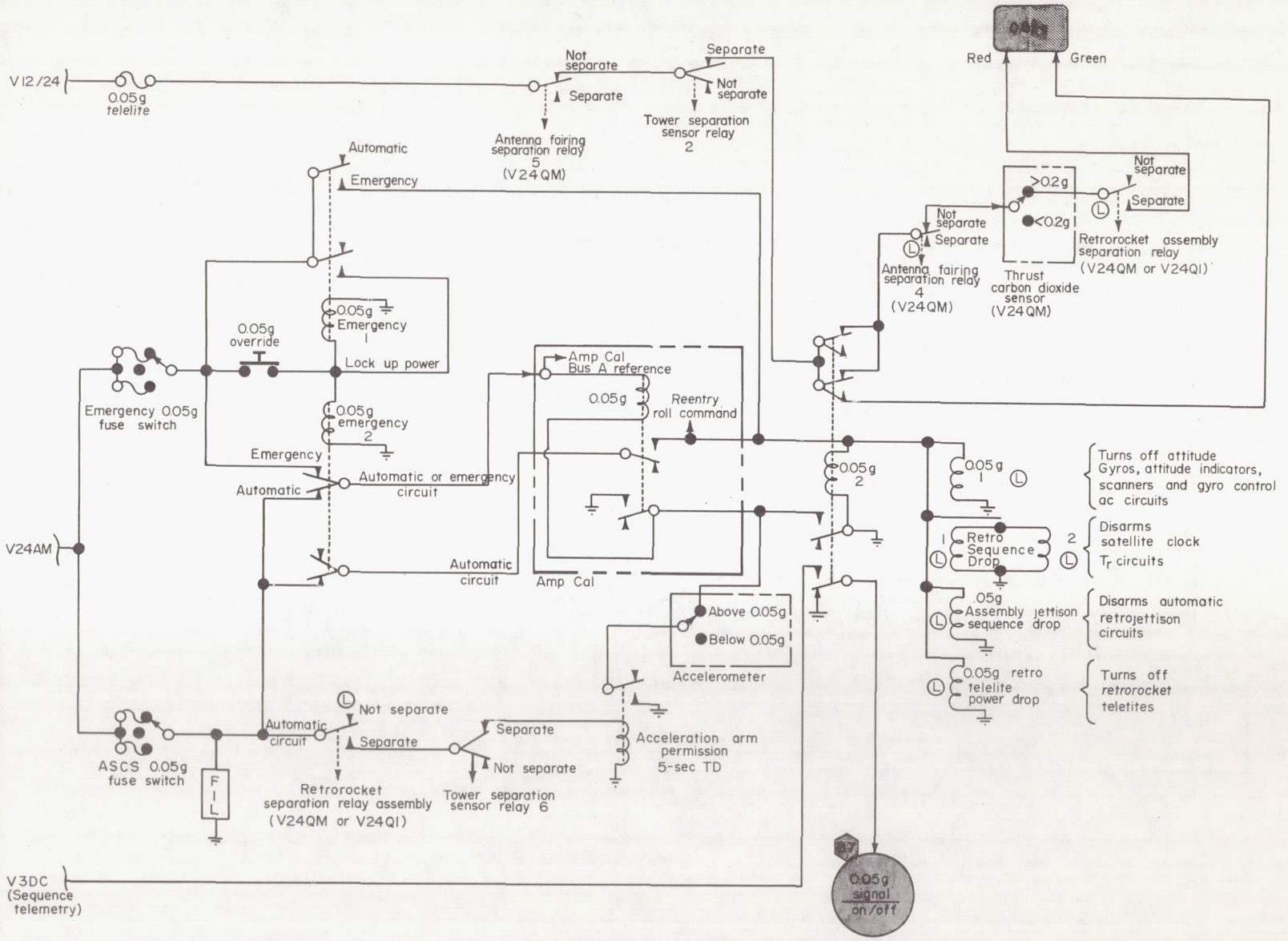



FIGURE 15-1.—Schematic diagram of 0.05g sequence.

*Table 15–III.—Sequence of Events for Abort Trajectories* [a]

| Time of abort, min:sec | Time of event, min:sec | | | | | | | | | | Recovery area |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tower jettison | Retro-pack jettison | Blackout (start) | Begin reentry (0.05g) | Reentry flight-path angle at 0.05g, deg | | Blackout (end) | Drogue parachute automatic deploy at 21,000 ft | Main parachute deploy at 10,000 ft | Landing | |
| | | | | | Space-fixed | Earth-fixed | | | | | |
| 00:00 | 00:07 | 00:00 | ---------- | 00:10 | ---------- | ---------- | ---------- | 00:10 | 00:10 | 01:15 | A |
| 00:10 | 00:19 | 00. 10 | ---------- | 00:22 | ---------- | ---------- | ---------- | 00:22 | 00:22 | 02:18 | A |
| 00:20 | 00:31 | 00:20 | ---------- | 00:34 | ---------- | ---------- | ---------- | 00:34 | 00:34 | 04:12 | A |
| 00:30 | 00:43 | 00:30 | ---------- | 00:46 | ---------- | ---------- | ---------- | 00:46 | 01:46 | 05:33 | A |
| 00:40 | 00:54 | 00:40 | ---------- | 00:57 | ---------- | ---------- | ---------- | 00:57 | 01:43 | 06:09 | A |
| 00:50 | 01:06 | 00:50 | ---------- | 01:08 | ---------- | ---------- | ---------- | 01:45 | 02:21 | 07:07 | A |
| 01:00 | 01:18 | 01:00 | ---------- | 01:24 | ---------- | ---------- | ---------- | 02:28 | 03:04 | 07:50 | A |
| 01:10 | 01:41 | 01:10 | ---------- | 01:41 | ---------- | ---------- | ---------- | 03:21 | 03:57 | 08:43 | A |
| 01:20 | 02:07 | 01:20 | ---------- | 02:07 | ---------- | ---------- | ---------- | 04:24 | 05:00 | 09:46 | A |
| 01:30 | 02:19 | 01:30 | ---------- | 02:42 | ---------- | ---------- | ---------- | 05:23 | 06:00 | 10:45 | A |
| 01:40 | 02:29 | 01:40 | ---------- | 03:36 | −9. 812 | −12. 94 | ---------- | 06:21 | 06:57 | 11:43 | A |
| 01:50 | 02:39 | 01:50 | ---------- | 04:46 | −17. 77 | −21. 93 | ---------- | 07:13 | 07:49 | 12:35 | A |
| 02:00 | 02:49 | 02:00 | ---------- | 05:48 | −19. 327 | −22. 81 | ---------- | 08:09 | 08:45 | 13:31 | A |
| 02:10 | 02:59 | 02:10 | ---------- | 07:05 | −20. 810 | −23. 01 | ---------- | 09:22 | 09:59 | 14:45 | A |
| 02:20 | 03:09 | 02:20 | ---------- | 07:30 | −20. 327 | −23. 07 | ---------- | 09:46 | 10:23 | 15:08 | A |
| 02:30 | 03:19 | 02:30 | ---------- | 07:22 | −19. 321 | −29. 18 | ---------- | 09:44 | 10:21 | 15:06 | A |
| 02:35. 7 | 03:24. 7 | 02:35. 7 | ---------- | 07:23 | −18. 801 | −21. 10 | ---------- | 09:40 | 10:16 | 15:02 | A |

[a] Times based on normal abort trajectories. For dispersed trajectory, the sequence changes.

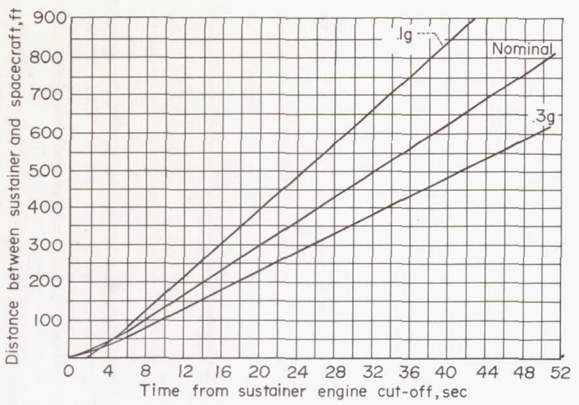



FIGURE 15–2.—Separation distance as a function of incremental time from SECO for different thrust sensing levels during nominal thrust conditions.

A flight plan was written which deviated from the normal Flight Plan in order to give the flight controllers experience in a contingency situation. A typical simulation picked up the last five passes of the spacecraft and during that time three flight controllers practiced simultaneously: one as the astronaut, one as the spacecraft communicator, and the third as the systems monitor.

In order to apply some of the defined procedures and to gain experience in the operation of the spacecraft systems, the Mercury procedures trainer at the Mercury Control Center (MCC) was used for launch and network simulations involving the MCC and the remote sites.

The primary objective of the launch simulations was to train the MCC flight controllers and the astronauts as a team by means of simulated launch experiences in order to develop their ability to perform correctly in any situation during the launch phase. In order to provide a realistic simulation, the launch trajectory was determined and prerecorded on tape with the additional capability of introducing an abort at any time by the operations staff, the astronaut, or a simulated automatic launch-vehicle abort. A complete voice network was exercised within the MCC and to the astronaut for complete familiarization of communication procedures. The telemetry backups of the MCC trainer allowed the flight controllers at MCC to view actions taken by the astronaut without a fixed simulation program. This practice resulted in a more realistic flight simulation than that afforded by the taped simulations used at the remote sites.

A full network simulation was first used for the MA–3 mission and was the basic final mission preparation tool utilized in all subsequent flights. The flight controllers were sent to their stations approximately 2 weeks before the scheduled launch date. Before the launch, three or four simulations were conducted to give the flight controllers experience in the use of correct procedures, coordination of the efforts of all support groups, and to exercise systems analysis capabilities. For the MA–9 mission, a real-time simulation of 18 orbital passes was performed to determine if any network operational difficulties existed which could affect the success of a long-duration mission. Thus, the problem areas were uncovered and solved before deployment for the MA–9 flight. After each simulation, there was a briefing in which the flight controllers explained their actions and any problems were reviewed. As a result, many changes to operational procedures and documentation were made.

The flight controller's detailed systems-analysis capability coupled with his understanding of the network equipment were the basic requirements necessary to perform his job. A brief examination of an orbital station passage will permit a better understanding of the real-time aspects of flight control.

Prior to radar and voice acquisition of the spacecraft at a particular site, the flight-control team at that site received systems status reports and monitored the air-to-ground transmissions between the spacecraft and other network sites. Trend plots were prepared and acquisition messages were received from the Goddard computers. The flight controllers at the site were generally briefed by the Mercury Flight Director prior to contact. At the expected acquisition and the approximate horizon time, the spacecraft communicator attempted UHF contact with the astronaut. Almost simultaneously the telemetry supervisor announced contact, and shortly thereafter, solid telemetry lock was obtained. The spacecraft communicator took the astronaut's systems status report; the aeromedical and spacecraft monitors evaluated systems status. After completion of the preliminary systems assessment, the flight-control team concentrated on any potential problem areas. If a problem existed, the data were rapidly evaluated and notification was sent to the MCC

and network by either voice or teletype. If time did not permit or if loss of communications with the MCC did not allow instructions to be given by the Flight Director, the flight controller had to be prepared to advise the astronaut. In order to provide the proper advice to the astronaut, the flight controller must rely on his knowledge of Mission Rules and spacecraft systems.

## Flight Control Chronology

The ability of the ground crew and the astronauts to work together as a team has contributed greatly to the success of Project Mercury. The astronauts' confidence in the flight-control organization and its ability to advise and direct their actions when problems occurred greatly simplified the flight control task.

### MR–3 AND MR–4

America's first manned space flight, Astronaut Shepard's flight (MR–3), was performed satisfactorily despite the tension involved with the first manned launch.

The flight-control operations of Astronaut Grissom's flight (MR–4) were smoother than those of the MR–3 flight, indicating the benefits obtained from flight-test experience. Information provided by all sources allowed a good analysis of the flight to be made in real time. From launch through landing, the flight was completely normal from the standpoint of flight control. However, early release of the spacecraft hatch caused the spacecraft to flood with water after landing and it was not recovered.

### MA–3, MA–4, AND MA–5

Although the MA–3, MA–4, and MA–5 flights were unmanned, they provided valuable experience to the flight-control team. In MA–3 and MA–4 a mechanical man was used to exercise the Environmental Control System. In MA–5, a chimpanzee was on board.

The MA–3 flight of April 25, 1961, was the first attempt to orbit a Mercury spacecraft; however, because of a launch-vehicle guidance malfunction, the mission was aborted shortly after lift-off. From the viewpoint of the flight control organization, a tremendous amount of experience was gained from this orbital attempt. For the first time, flight controllers were deployed to remote sites. As a result, many difficulties were experienced with logistics and communications. Originally, the MA–3 mission was to have been a suborbital flight, but 3 weeks prior to the actual launch, the mission profile was changed to an orbital flight. As a result, problems were encountered with transportation, currency, passports, and travel orders.

The remote-site flight controllers on the MA–4 mission were able to acquire, evaluate, and transmit real-time data; however, problems developed because of the delay in preparation of summary and postpass messages. The major concern during this mission was the inability of the sites to acquire C- and S-band radar tracking. The inability of the sites to acquire C-band radar tracking was attributed to poor spacecraft antenna radiation pattern which was corrected for later flights. Failure to track S-band at several sites was determined to be the result of personnel error. This difficulty was corrected by further training of the maintenance and operational personnel at the remote sites.

For the MA–5 mission, the telemetered data from the spacecraft were of good quality and all sites received total coverage. Data transmission from all sites was good, and the Goddard conference loop was utilized for the first time to provide real-time voice data to MCC from sites that had access to a telephone cable for voice capability. The MA–5 mission was originally scheduled for a three orbital-pass mission, but a series of problems caused termination of the flight at the end of the second pass. The apparatus used to measure the chimpanzee's psychomotor responses malfunctioned. In addition, there was a suit and cabin temperature increase; however, a control-system malfunction causing high fuel usage was the reason for termination of the flight. If the flight had been allowed to continue an insufficient quantity of fuel would have been available for retrofire and reentry. The decision to terminate was made and executed in 12 seconds in order to be able to bring the spacecraft into a planned landing area. The decision was made, and the California spacecraft communicator commanded retrofire. The MA–5 flight proved to be a fine example of the importance of being prepared

to make a real-time decision and to act on it immediately.

### MA–6

Because MA–6 was the United States' first manned orbital flight, the events which occurred are quite familiar. At the beginning of the second orbital pass over Cape Canaveral, the telemetry data indicated that the heat shield had become unlatched. This indication caused a great deal of concern to the ground crew because of the possibility that the heat shield was loose. While he was in contact with the Hawaii station during the third pass, Astronaut Glenn was asked to put the landing-bag switch in the automatic position to determine if the landing-bag deploy light would come on. The astronaut did not get an indication which meant that the problem was probably an instrumentation failure. However, after further analysis it was decided that the safest approach was not to jettison the retropackage so that the retropackage straps could hold the heat shield in its proper position during reentry until sufficient aerodynamic force was exerted on the shield to hold it in place. Another problem was a partial failure of the automatic stabilization and control system (ASCS), but this problem was handled very adequately by the astronaut's using manual backup and fly-by-wire (FBW) control.

### MA–7

For the MA–7 mission, the air-ground contact procedures were reviewed and negative reporting procedures were initiated to eliminate unnecessary conversation with the pilot and network teletype traffic. The only major systems problem was the improper functioning of the ASCS. Astronaut Carpenter was forced to perform a manual retrofire since attitudes could not be controlled by the ASCS.

### MA–8

As far as the flight was concerned, the MA–8 mission was a "textbook flight," in which no problems of any importance developed. As a result of the excellent performance of Astronaut Schirra and the spacecraft, the flight-control task became one of monitoring, gathering data, and assisting the astronaut with the Flight Plan.

### MA–9

*Permission.*—The flight controllers began deploying for the MA–9 mission on April 30, 1963, and by May 5 all teams were at their sites.

Onsite prelaunch preparation began with launch simulations at Cape Canaveral and Bermuda. A total of ten launch simulations were conducted, five on May 2 and five on May 4.

The network simulations began on May 7 with two simulations being conducted on that day. In the first simulated mission, the systems-analysis capabilities of the flight controllers were exercised by a failure of the FBW high thruster control followed by a loss of cabin and suit pressure integrity. The second simulated mission contained a 1-second-late sustainer engine cut-off resulting in an overspeed insertion which caused a higher than normal apogee. These conditions tested the ability of the flight dynamics officer and retrofire monitors to calculate new reentry areas and retrofire times. Also, all the flight controllers were tested in their ability to adjust to an abnormal sequence of acquisition-of-signal and loss-of-signal times.

On May 8 the first simulation contained noisy and intermittent telemetry data, and the flight controllers were required to obtain data from backup recorders. The second mission contained a leaking regulator in the manual fuel pressurization system. During the second orbital pass a Military alert was simulated, which caused a reevaluation of the Mission Rules concerning loss of two-way communication with the spacecraft.

The first mission of the third day of simulations, May 9, was primarily an aeromedical monitor exercise with the astronaut experiencing a simulated heart attack. The second mission of the same day contained another systems problem with a failure of the main fans inverter and the standby inverter. Reentry was initiated by the California station when the Guaymas station experienced a failure of the air-ground transmitting capability. Landing was approximately 1,100 miles downrange from nominal because of a failure of the third retrorocket to fire.

The last simulation was on May 12 and an attempt was made to exercise both the range maintenance and operations personnel and the

flight controllers. During the mission the 10.5-kc voltage-controlled oscillator drifted in frequency, and this action required the telemetry ground-station operators at the remote sites to adjust the discriminator center frequency control constantly, and the flight controllers to analyze the pulse-amplitude-modulation wave train on the backup recorders.

Throughout the simulations, the intent was to provide the flight controllers and support personnel with the atmosphere of an actual mission. For that reason, each mission began with liftoff, and reentry was determined by the condition of the spacecraft and the astronaut without regard to any set pattern of orbital or reentry simulations.

The performance of the site simulation teams, and particularly the astronaut simulators, was outstanding throughout the MA–9 simulations. Probably the most often heard criticism of the MA–9 simulations was the fact that 3 consecutive days of network simulations were scheduled. This rigorous schedule imposed extremely long hours on the maintenance and operations personnel as well as the flight controllers.

*Mission.*—The network countdown for MA–9 was initiated on May 14 at 2:00 a.m. e.s.t. The spacecraft–launch-vehicle countdown proceeded normally. The network radar-computer data test was completed on schedule, and the mandatory equipment at all stations was operating satisfactorily with the exception of the Bermuda FPS–16 radar, which had failed the slew tests in both azimuth and range. The slew tests were scheduled to be rerun for Bermuda, and the "C" computer at Goddard was standing by to check the Bermuda data. Bermuda estimated that it would take an hour to isolate the problem. Reruns of the radar-computer data tests indicated the azimuth and elevation data were good; however, some dropouts were experienced in range.

At T–60 minutes, a series of short-duration holds, eventually totaling 2 hours, were called because of problems with the diesel generator used for moving the gantry. The fuel system on the diesel was changed and the count was resumed at 9:09 a.m. e.s.t.

The Bermuda radar had passed the test performed during the hold; however, there was still a 14-percent error rate in the range data. Continual status reports were obtained from Bermuda, and the performance of the radar was marginal for the T–45 minute liquid-oxygen status check. A final slew test was performed with Bermuda at T–20 minutes, and the error rate on these data was unacceptable. It was determined at this time that the radar would not be able to support the mission and the launch attempt was canceled at 10:00 a.m. e.s.t.

The Bermuda station began immediate troubleshooting of the FPS–16 system, and the Goddard computer was placed on a standby status to run data slew tests with the radar when it was repaired. The problems were isolated to the preamplifier in the azimuth digital data channel and the shift register in the range digital data channel.

The count was recycled for 24 hours and the network count was resumed at 2:00 a.m. e.s.t. on May 15. All primary network systems were operational when the countdown was initiated.

The confidence summaries transmitted by the network to verify the site patching and calibrations were very good. No major discrepancies were noted in the network voice communications; however, Zanzibar, Canton Island, Rose Knot Victor, and Coastal Sentry Quebec stations were influenced by propagation and several repeats were required from the stations. The May 15 countdown was continuous except for a short hold for the launch vehicle ground support equipment. The countdown was resumed within approximately 4 minutes and liftoff occurred at 8:04:13 a.m. e.s.t.

The powered-flight phase was normal, and all launch events occurred at the expected time. The performance of the guidance and data systems was excellent. A clear go condition was evident at insertion, and orbit lifetime was not considered to be a problem. All vehicle systems performed satisfactorily through launch and the air-ground communications were better than those of the previous mission.

After spacecraft separation from the launch vehicle, the astronaut manually performed a FBW-low turnaround maneuver. Shortly after the completion of this maneuver, the Bermuda station advised the MCC that they had observed approximately a 6° F rise in cabin and suit dome heat-exchanger temperatures. The astronaut was informed of this situation and increased the coolant flow. When the astronaut

acquired voice communications with the Canary Islands station, he said that the dome temperature warning light had come on, which indicated that the suit dome temperature was below 51° F. The astronaut was required to monitor this temperature throughout the flight and to make frequent adjustments to the coolant control valve. The cabin temperature rose from 94° F at launch to approximately 118° F when the spacecraft passed over Muchea as a result of the exit heat pulse; subsequently, this temperature began to decrease slowly to a value of between 90° F and 100° F. All spacecraft systems were functioning normally, and MCC advised the Guaymas station to transmit to the astronaut the go decision for seven orbital passes. Throughout the flight, cabin air temperature appeared to vary slightly as a function of the spacecraft a–c power configuration. During the periods when the ASCS 115v a–c inverter was powered for an appreciable time, the temperature rose to a maximum value of 105° F; and when this inverter was powered down, the temperature decreased slowly over a period of several orbital passes to a value between 85° F and 95° F.

The first discrepancy occurred over Cape Canaveral at the beginning of the second orbital pass. When the telemetry was commanded by the ground, a series of repetitive telemetry calibration signals occurred. It was decided that the programed telemetry calibration function would be turned off during the sleep period so that it would not interfere with normal telemetry.

At the beginning of the fifth orbital pass, the astronaut turned the cabin fan and cabin heat exchanger off as indicated by the Flight Plan. It was noted subsequently that turning off the cabin cooling did not materially affect the cabin temperature. The astronaut opened the outlet port of the condensate trap, and whenever this trap was activated, it is believed that the system performed satisfactorily. It was noted early in the flight that the actual power consumption was less than predicted. This surplus electrical power was utilized to obtain more beacon tracking during the later phases of the flight. The C-band beacon was powered up three times prior to passes over the Hawaii station to enable tracking by the Range Tracker ship.

Fuel usage was also less than expected, and all reports indicated that the astronaut was managing his fuel supplies exceptionally well. The astronaut made several attempts to deploy the tethered balloon, in support of air-density studies and visual tests; however, all attempts were unsuccessful. After ground analysis of this system, it was decided that no further attempt would be made to deploy the balloon.

The most serious trouble of the flight was reported over Hawaii during the 19th orbital pass. The Hawaii spacecraft communicator contacted the astronaut and received a report that the 0.05g green telelite had come on and that the astronaut had placed the ASCS 0.05g fuse switch and the emergency 0.05g fuse switch to off. The main concern at MCC was to establish the state of the amplifier-calibrator (auto pilot) unit and to determine what functions of the ASCS were lost as a consequence. There was no need for planning early mission termination at this time as no Mission Rules had been violated and there was an effective control mode remaining on both the automatic and manual control systems.

After analysis and discussion of the problem, it was decided that the first step was to have the astronaut power up the ASCS bus as the spacecraft passed over Guaymas. Subsequently, over Cape Canaveral, the gyros were slaved to the horizon scanners; and after about a minute of operation, no gyro or scanner deviation from the gyro caged condition was noted. This situation indicated that the gyro and scanner power actually was off and that the 0.05g circuit was latched up. It was realized at this time that a manual retrofire would be required and that a checklist must be prepared for the astronaut. The remote-site flight control personnel on standby status were called to their stations and advised to be prepared to attempt to relay communications to the astronaut if directed by the MCC.

While he was in contact with the Coastal Sentry Quebec, the astronaut was requested to turn on the telemetry and C-band beacon to allow the Range Tracker to check its radar data. These data were very important since the retrofire maneuver would be performed manually. While the spacecraft was passing over the Hawaii station, the astronaut was requested to place the ASCS 0.05g and emergency



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0.05g fuse switches to the on position and to select the ASCS automatic mode to verify the 0.05g event. If the spacecraft began to roll as it would normally do when the 0.05g indicators were valid, the ASCS would be latched in the reentry mode. The astronaut verified this roll rate and the 0.05g event which were again confirmed by telemetry over the Guaymas station.

At this point the flight controllers knew the exact configuration of the ASCS logic and the required configuration for reentry. After completion of these tests, it was determined that the ASCS would provide proper attitude control and roll rate for reentry after the normal 0.05g event time. The manual retrofire checklist was completed and thoroughly reviewed by the MCC flight control team. This checklist was relayed to the spacecraft via the spacecraft communicator on the Coastal Sentry Quebec and written down by the astronaut. The astronaut was advised to "take Green for go" which was a coded means of telling him to take a dexadrine pill. The purpose for taking the pill was an added precaution to be sure that he was alert for the manual retrofire maneuver. The flight surgeon was not concerned over the astronaut's condition but he was not certain the astronaut was thoroughly rested from his sleep. On acquisition by the Zanzibar station on the 22nd orbital pass, the astronaut reported that the ASCS inverter had failed and the standby inverter would not start. These failures meant that the pilot could no longer have automatic control after 0.05g but would have to introduce the reentry roll rate manually. The failure of the inverters to start required that a revision be made to the checklist previously transmitted to the astronaut. The revision consisted of changing only one switch position on the earlier checklist.

Prior to retrofire, the Coastal Sentry Quebec acquired the spacecraft and the reentry procedures were reviewed. The astronaut was given time hacks at retrofire minus 60 seconds, minus 30 seconds, and a 10-second terminal countdown. The telemetry immediately confirmed the retrofire and the astronaut indicated that his attitudes were good and confirmed that all three retrorockets had ignited. Reentry blackout was confirmed by the Range Tracker ship within 2 seconds of predicted time which indicated that the landing point would be close to nominal.

The network flight-control teams performed well during this flight. Communications between the ground and the astronaut were precise and conveyed the necessary information. The flight control teams utilized the proper contact and reporting procedures that were developed for this flight test. The operations messages provided much useful real-time data, and no difficulty existed in determining the precise status of the spacecraft, the astronaut, or the mission. The entire mission period from deployment through recovery was an extremely smooth and well coordinated effort. The cooperation between the flight astronauts and the flight control personnel had a significant influence on the success of the MA–9 mission.

## Concluding Remarks

The flight control organization has played a significant role in the first space flights and has made a major contribution to the success of the Mercury program. A wealth of experience and information has been gained from the project. Some of the more important are as follows:

(1) Documentation used by flight control had to be easy to update, contain detailed information, yet be put together in such a manner that the information could be found quickly in real time.

(2) People could not be borrowed from other organizations on a part-time basis to be flight controllers. It not only disrupted their own organizations but prevented them from being able to devote the required amount of time to the flight control task. As a result, it was learned that full-time flight controllers were a necessity.

(3) It was also discovered that a flight controller had to have the following special qualification: The flight controller must be a technically trained individual. It became apparent he should be an engineer or oriented toward engineering with a wealth of experience in system analysis.

(4) It was also found that a continuing program of training was necessary to keep flight controllers proficient in knowledge of spacecraft systems and operation procedures.

(5) The network and launch simulations held prior to the actual mission were found to be a necessity. In simulations, mistakes are made

and corrected. Simulations are run until the entire network is functioning as a team and complete confidence is gained in the ability of the flight controllers to respond correctly to any emergency.

(6) Because of the experience gained in Mercury it has become obvious that the more complex missions of Gemini and Apollo will require more automation. In order to be able to process the information in real time and arrive at a proper decision, it is necessary that more data processing aids be utilized.

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# 16. RECOVERY OPERATIONS

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## Summary

The basic philosophy for the recovery phase of Project Mercury was to provide a positive course of action for any conceivable landing situation that could develop, and to provide recovery support according to expected needs and the probability of such situations occurring. Throughout the program this philosophy was continuously reviewed as experience was gained and mission complexity increased. Although certain improvements and changes were made in recovery equipment and techniques, there was no significant change in the basic philosophy originally adopted and all recovery operations were highly successful.

## Introduction

This paper presents a general review of the recovery planning and operations conducted for Project Mercury. A discussion of the overall recovery philosophy and a brief description of the location and retrieval techniques that were planned and used for spacecraft recovery are included.

## Recovery Philosophy

In reviewing Project Mercury recovery operations, it is appropriate to go in some detail into the basic philosophy upon which recovery planning was based. The foundation of this philosophy was the premise that a positive course of action to provide safe recovery of the astronaut would be planned for all conceivable landing situations, including provisions for the most expeditious return of the spacecraft. The type of action to be taken was determined by the probability of occurrence and location of the landing. For this purpose, possible landings were divided into five general categories, as follows:

(1) The first category included landings which might occur during that period of the mission from arming of the launch escape system prior to launch until that point after launch where an abort would result in a landing within 12 miles of the launch site at Cape Canaveral. This area is referred to as the "Launch Site Abort Landing Area."

(2) Aborts subsequent to this time and prior to insertion of the spacecraft into orbit would result in a landing in one of several planned "Pre–orbital Abort Landing Areas."

(3) After the spacecraft was committed to orbit, Planned Landing Areas were selected so that a landing could be made in the vicinity of predeployed recovery forces at approximately 100–minute intervals through the flight.

(4) The "Primary Planned Landing Area" was that area where the flight would be ultimately terminated, if possible.

(5) Finally, a landing might occur at any place along the ground track as a result of an emergency situation. This emergency might not permit the spacecraft to reach one of the planned landing areas and, therefore, would result in a contingency recovery situation. A location capability was provided along the entire ground track of the flight. To reduce the search area, when some choice of spacecraft landing point remained available, so–called preferred contingency landing areas were designated. These areas were intermediate locations along the ground track between planned landing areas that either were adjacent to land areas or location forces.

The degree of support in terms of the number of ships, aircraft, and personnel planned for

each of these landing areas was determined by the degree of probability that a landing might occur. Hence, since the greatest probability of a landing was in the primary landing area, the greatest level of support was provided here. The amount of support provided for contingency landings was considerably less, consistent with the much lower probability of a contingency landing.

It can readily be seen that extensive recovery forces were necessary to support this philosophy. In keeping with the National Space Act, maximum utilization was made of Department of Defense (DOD) capabilities, with a minimum of interference with their normal operational functions. (See paper 9.) Although standard DOD ships and aircraft could be utilized, the requirement existed for specialized equipment to support the Project Mercury recovery operation. The special equipment necessary was provided by the NASA. Indoctrination and training programs were conducted to establish and qualify recovery procedures and familiarize the forces involved with the use of specialized equipment and techniques.

This basic philosophy for recovery planning was continuously reviewed throughout the program, particularly in light of experience gained from each successive mission and with regard for the increasing complexity of forthcoming missions. Nothing developed to justify any significant change in the basic philosophy originally adopted, although certain improvements and changes were made in the equipment and techniques used in support of the recovery plans.

There are three major phases in the recovery operation: location, retrieval, and postrecovery activities. The location phase began with the notification of the recovery forces that a landing was imminent and the general area in which the landing could be expected. As the landing progressed from retrofire through reentry to actual touchdown, information from the Mercury Worldwide Network provided a predicted landing point.

Search aircraft, both airborne and on station in the planned landing areas or staging from a contingency deployment site, then proceeded toward this point conducting an ultra-high frequency/direction finding (UHF/DF) electronic search for the spacecraft recovery beacon or personal survival beacon enroute. Upon receiving a signal, they would then home in on it until close enough to conduct a visual search, aided in daylight by dye expelled from the spacecraft or by a flashing light at night.

In the absence of a reliable network landing-point prediction, alternate sources could be called upon for such information. Some geographical areas were blanketed with either HF/DF or SOFAR networks which could determine the general location of spacecraft landing within their limits of coverage. For landings outside those areas, where no other specific location information was available, location would be accomplished by searching the ground tracks along which the landing could have occurred.

In the early part of the project it was desirable that the retrieval of the spacecraft could be accomplished by either ships or helicopters. All ships utilized in the program had the capability of lifting the spacecraft from the water. Those ships not having a lifting crane could, with a minimum of modifications, utilize their existing boat davits to lift the spacecraft (fig. 16–1). Helicopters with the capability of lifting the spacecraft were equipped with special hooks and lifting slings (fig. 16–2) to provide them with a man-rated retrieval system. Early in the project, when uncertainties about the condition of the spacecraft and occupants were the greatest, helicopters were considered the most desirable means of retrieval because of their ease of access to the scene of the landing and the rapid method of spacecraft retrieval.

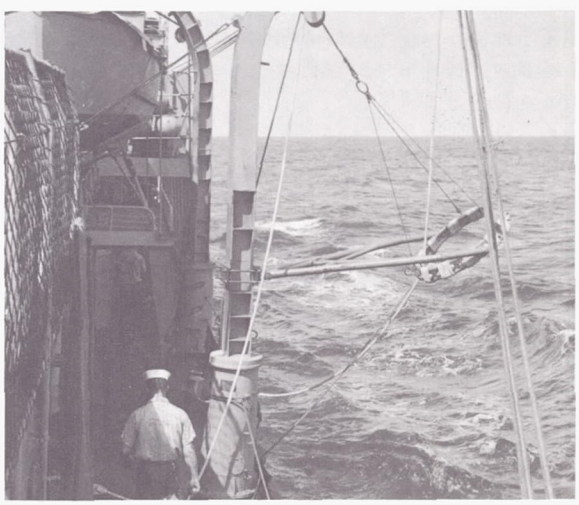


FIGURE 16–1.—Modified davit and hold-off rig on destroyer.




FIGURE 16–2.—Spacecraft being lifted from water by helicopter.

Procedures were established whereby the astronaut would be retrieved by the same helicopter that picked up the spacecraft. It was not possible to have helicopters in all the landing areas, however; so in those areas of lower landing probabilities only ships, with retrieval capability, were provided.

This philosophy existed throughout the early development flights at Wallops Island and through the Redstone program. The helicopter retrieval method by its very nature required maximum demands on both personnel and recovery equipment. The experience of MR–4, when the helicopter was able to hook the spacecraft but was unable to retrieve it successfully, pointed out the limitations of this method. It was apparent then that this method exposed itself to many hazards that were not desirable.

During the early development flights, a concurrent program for development of an auxiliary flotation collar was underway. The attachment of this collar (fig. 16–3) to the spacecraft



FIGURE 16–3.—Auxiliary flotation collar.

provided increased flotation capability to the spacecraft under all water-landing conditions. The collar also provided a suitable working platform for rendering assistance to the astronaut, and it also served as a platform from which the astronaut could be retrieved by helicopter. The spacecraft, even with an open hatch, was seaworthy when fitted with the auxiliary flotation collar.

After the suborbital flights had been completed, the following technique was instituted as the primary retrieval method. After spacecraft location, either swimmers or pararescuemen, deployed by helicopter or aircraft, would attach the flotation collar to the spacecraft. The astronaut could then exit the spacecraft or remain within as he chose. Medical assistance could be given and spacecraft systems could be secured as well. Retrieval of the spacecraft was to be made by surface ships and use of the helicopters was primarily intended for retrieval of the astronaut only.

Following retrieval, the post-recovery activities of the astronaut include: personal medical attention as required; physical examinations; a medical debriefing and technical debriefings with trained specialists in these fields; and scheduled rest periods. Following retrieval of the spacecraft, trained personnel secured the spacecraft systems, conducted initial postflight

inspections, and removed the onboard data for rapid delivery to Cape Canaveral. The spacecraft was then transported by special airlift to Cape Canaveral for detailed inspection and analysis.

The recovery plan for contingency area landings included the deployment of pararescue men by parachute as soon as possible after the spacecraft had been located by search aircraft. For water landings the auxiliary flotation collar, also dropped by parachute from the search plane, was then attached to the spacecraft so that the astronaut could emerge to await rescue. Rescue of the pilot and retrieval of the spacecraft were then to be accomplished by the most expeditious means available under the circumstances. Had the spacecraft been located by an aircraft not carrying pararescuemen, or had local conditions precluded their jumping to the spacecraft before the aircraft had to leave the landing area, drop buoys were provided to assure relocation of the spacecraft. These buoys were fitted with radio beacons compatible with the UHF/DF equipment in the search aircraft.

Many other preparations were made to insure a safe and rapid recovery. For example, a worldwide recovery communications network was established utilizing both DOD and commercial facilities. This extensive communication network was required to provide for rapid reporting and coordination among the recovery forces, Area Command Centers, and the Recovery Control Center at Cape Canaveral. A worldwide weather reporting and analysis system was also established to provide pertinent meteorological data in the recovery areas, so that action could be taken to delay the launch or move the recovery area in the event of adverse weather conditions.

Table 16–I provides pertinent recovery facts for all Project Mercury missions and shows how the various preparations described above were useful in each case.

*Table 16–I.—Summary of Recovery Operations for Project Mercury*

| Flight | Launch date | Description | Range, nautical miles | Recovery forces | | Location method | Retrieval by | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | | | Ships | Airplanes and helicopters | | | |
| Little Joe series (9 flights) | October 4, 1959, to April 28, 1961 | Suborbital | 10 to 169 | 3 to 4 | 3 helicopters (typical) (plus 2 airplanes on LJ II) | Visual and electronic | Ship *or* helicopter | Little Joe and Beach Abort-Development flights made from Wallops Island. Retrieval by helicopter or ship was accomplished on all successful flights and qualified the recovery methods. |
| Big Joe I | September 9, 1959 | Suborbital | 1,300 | 13 | 7 airplanes 3 helicopters | Reentry glow, SOFAR, electronic | Ship | Planned for 1,831 nautical miles but resulted in an undershoot with landing at 1,300 nautical miles—about halfway between two destroyers. No tracking information is available; but on the basis of visual sightings of reentry by three destroyers and confirmation of the landing point by a SOFAR bomb fix (T+2 hr), search aircraft located the spacecraft after acquiring beacon contact (T+3 hr) and directed a destroyer in for the retrieval operation (T+8 hr). |

*Table 16–I.—Summary of Recovery Operations for Project Mercury*—Continued

| Flight | Launch date | Description | Range, nautical miles | Recovery forces [a] | | Location method | Retrieval by | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | | | Ships | Airplanes and helicopters | | | |
| MA–1 | July 29, 1960 | Suborbital (unmanned) | 4.85 | 8 | 5 airplanes<br>3 helicopters | Visual and electronic | Salvage ship | Flight-vehicle structural failure shortly after launch. Salvage operations recovered most of spacecraft components. |
| MR–1 | November 21, 1960 | Suborbital (unmanned) | 0 | 8 | 6 airplanes<br>3 helicopters | Visual | | Launch-vehicle shut down immediately after lift-off. No recovery required. |
| MR–1A | December 19, 1960 | Suborbital (unmanned) | 204 | 8 | 4 airplanes<br>4 helicopters | Visual | Helicopter | Recovered by helicopter which was operating from landing ship, dock. |
| MR–2 | January 3, 1961 | Suborbital (chimpanzee) | 363 | 8 | 6 airplanes<br>5 helicopters | Electronic | Helicopter | Retrieved by helicopter which was operating from a landing ship, dock, although a destroyer was on the scene. A contingency recovery operation (overshoot) with damaged spacecraft near sinking at time of retrieval. |
| MA–2 | February 21, 1961 | Suborbital (unmanned) | 1, 244 | 8 | 14 airplanes<br>5 helicopters | Electronic | Helicopter | Successful suborbital flight. Helicopter retrieval and return to landing ship, dock. |
| MA–3 | April 25, 1961 | Orbital (unmanned) | 0. 25 | 15 | 12 airplanes<br>7 helicopters | Visual | Helicopter | Guidance system failure, destructed by RSO resulting in spacecraft landing off-shore near Cape Canaveral. Launch-site helicopters successfully retrieved spacecraft. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| MR–3 | May 5, 1961 | Suborbital (manned) | 263 | 8 | 7 airplanes<br>7 helicopters | Visual | Helicopter | First manned mission. Spacecraft and astronaut retrieved by carrier-based helicopter less than 11 minutes after landing. |
| MR–4 | July 21, 1961 | Suborbital (manned) | 262 | 8 | 7 airplanes<br>7 helicopters | Visual | Helicopter | Second manned mission. Spacecraft hatch prematurely opened and astronaut escaped into water. Helicopter hooked onto spacecraft but could not retrieve it. Astronaut was recovered by another helicopter and returned to carrier. |
| MA–4 | September 13, 1961 | Orbital (unmanned) | 1 orbital pass | 9 | 34 airplanes<br>6 helicopters | Visual | Ship | Planned one orbital-pass mission. Retrieval by destroyer after being located by aircraft in nominal landing area. |
| MA–5 | November 29, 1961 | Orbital (chimpanzee) | 2 orbital passes | 18 | 49 airplanes<br>9 helicopters | Electronic | Ship | Planned three orbital-pass mission terminated in planned landing area at end of two passes. Spacecraft and occupant (chimpanzee) successfully recovered by destroyer following aircraft location. |
| MA–6 | February 20, 1962 | Orbital (manned) | 3 orbital passes | 24 | 49 airplanes<br>14 helicopters | Visual | Ship | First manned orbital mission. Spacecraft landing in the prime recovery area at the end of third orbital pass. Nearby destroyer retrieved the spacecraft and astronaut. |

[a] These figures do not include nonoperating contingency or backup aircraft.

*Table 16–I.—Summary of Recovery Operations for Project Mercury*—Concluded

| Flight | Launch date | Description | Range, nautical miles | Recovery forces [a] | | Location method | Retrieval by | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | | | Ships | Airplanes and helicopters | | | |
| MA–7 | May 24, 1962 | Orbital (manned) | 3 orbital passes | 20 | 49 airplanes 14 helicopters | Electronic | Helicopter (astronaut) Ship (spacecraft) | Planned three orbital-pass mission terminated in a landing 250 miles downrange of the planned landing point. A contingency recovery operation included pararescue deployment approximately on hour after landing. Astronaut recovery by helicopter and spacecraft retrieval by destroyer. |
| MA–8 | October 3, 1962 | Orbital (manned) | 6 orbital passes | 26 | 69 airplanes 14 helicopters | Visual | Ship | Planned six orbital-pass mission. Landing within sight of prime recovery carrier. Spacecraft provided with auxiliary flotation collar installed by helicopter-deployed swimmer teams. Spacecraft and astronaut retrieved by carrier. |
| MA–9 | May 15, 1963 | Orbital (manned) | 22 orbital passes | [b] 26 | 110 airplanes 14 helicopters | Visual | Ship | Planned twenty-two orbital-pass mission. Landing within sight of prime recovery carrier. Spacecraft was provided with auxiliary flotation collar installed by helicopter-deployed swimmer teams. Spacecraft and astronaut retrieved by carrier. |

[a] These figures do not include nonoperating contingency or backup aircraft.

[b] This number does not include 2 ships in the Middle East.

### MA–9 Recovery Operations

A brief description of the recovery plan and operations for the MA–9 mission will serve as a typical example of the Project Mercury recovery, based on the philosophy and techniques previously described.

Prior to the MA–9 launch, all recovery forces were reported to be on station and ready. After insertion of the astronaut into the spacecraft, a pad-emergency egress team was standing by to assist the astronaut in the event he had to leave the spacecraft for some emergency that did not require activation of the launch escape system. This team included medical personnel, spacecraft specialists, and fire fighters in special vehicles.

Special recovery teams were located in the launch site abort landing area to provide rapid access to the spacecraft for landings resulting from possible aborts utilizing the launch escape system during the late countdown and early phase of powered flight. Because of the variations in the type of terrain and proximity to the ocean in the launch site area, these teams utilized helicopters and amphibious vehicles. Small craft operated in the Banana River, and standing by offshore were several salvage ships. Winds at the launch site were measured and abort landing positions were computed and plotted. These plots were used to evaluate possible landing hazards prior to committing the spacecraft to a launch and to optimize the positioning of these recovery forces.

Areas A through F, the pre-orbital abort landing areas stretching across the Atlantic Ocean and shown in figure 16–4, supported all probable landings in the event an abort was initiated at any time during powered flight. Landings in Areas A and B would result from an abort at velocities up to about 24,000 feet per second, and Areas C, D, E, and F would support aborts at higher velocities where programed use of the retrorockets would provide for selection of the landing area.

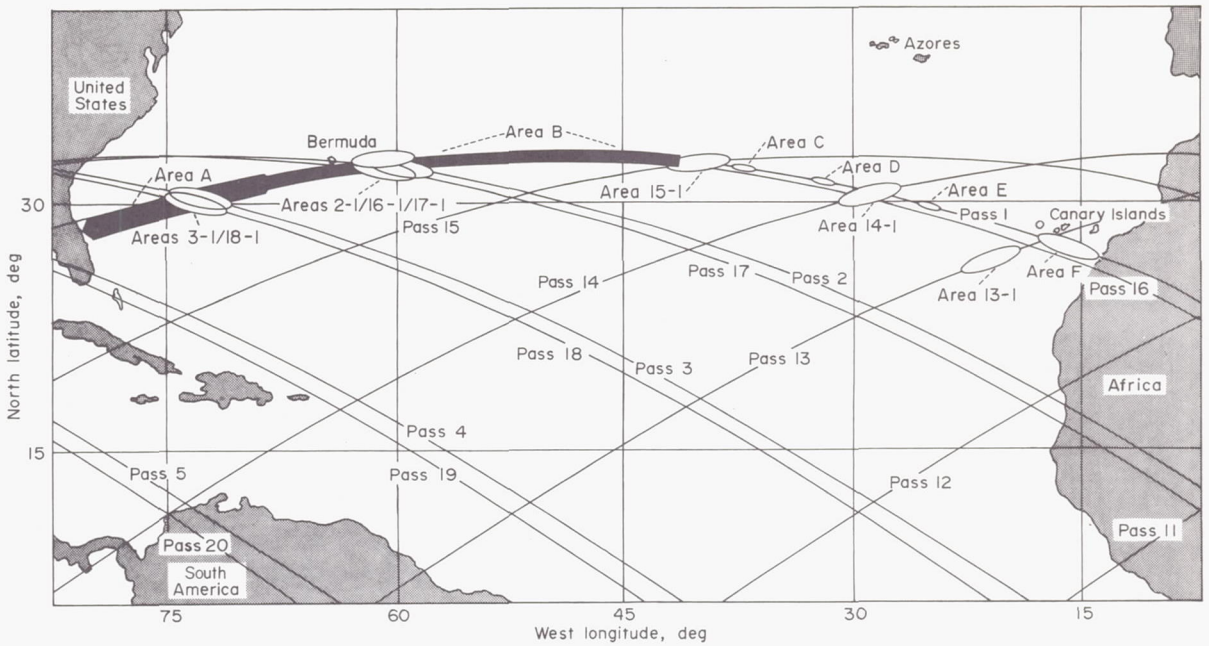
Also shown in figure 16–4 are the numbered landing areas. These locations are planned landing areas or areas in which the spacecraft could have landed if the flight had been terminated prior to the planned end of the mission. The planned landing areas were spaced so that the spacecraft would pass over one of them approximately every 100 minutes or about once per orbital pass.

Recovery forces were deployed within these landing areas so that location and assistance could be provided within a period of from 3 to 9 hours after spacecraft landing. This period, denoted as the recovery "access time," was a function of the planned deployment of recovery forces in a given area and varied according to the probability of a spacecraft landing within that area. Selection of landing areas at spacecraft ground track intersections permitted certain recovery units to move from one area to another during the flight and thereby provide support in several landing areas.

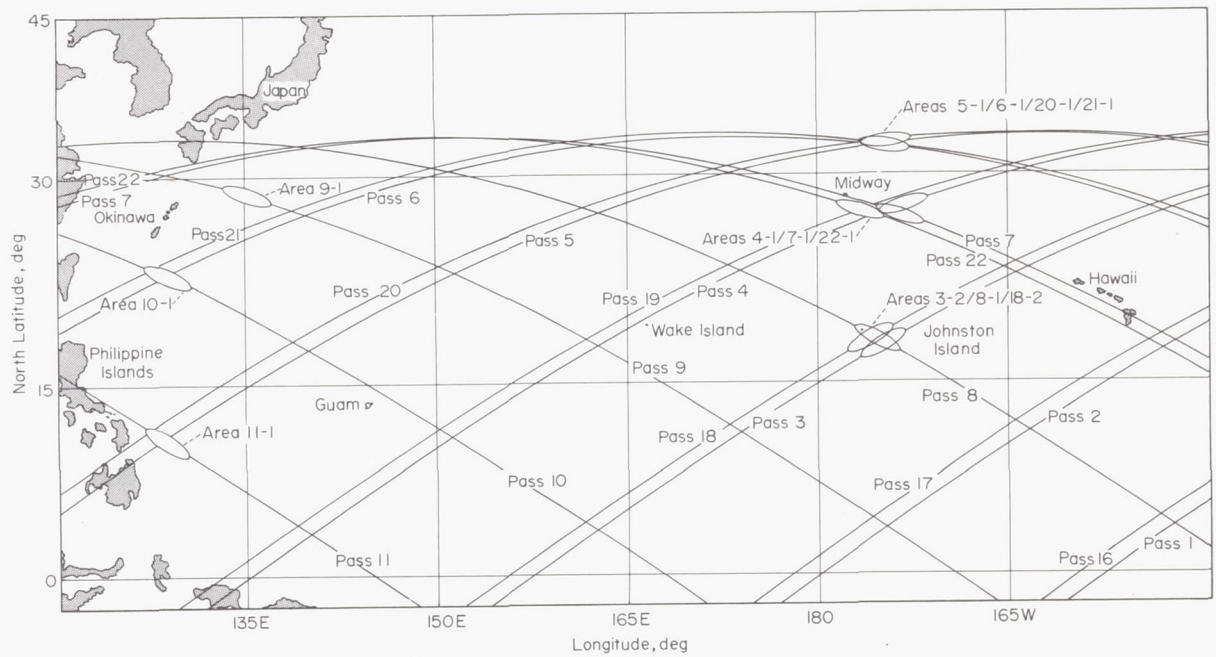
Throughout the mission, flight progress was continuously monitored, and periodically during the mission, decisions based on spacecraft and astronaut conditions were made to continue the flight. Obviously, a higher probability of landing is associated with the landing areas immediately following these decision points. Landing Areas 2–1 and 17–1 in the Atlantic and Area 7–1 in the Pacific were such areas and were referred to as "go—no–go" areas. Area 22–1, the Primary Planned Landing Area for a nominal flight, was located in the Pacific about 70 nautical miles southeast of Midway Island and adjacent to Area 7–1. Since the probabilities of landing in these two areas, 2–1/17–1 in the Atlantic and 7–1/22–1 in the Pacific, were considered to be higher than for other planned areas, recovery-support helicopters operating from aircraft carriers were provided for a more rapid access to the spacecraft and astronaut after landing.

A total of 23 ships and 44 aircraft were employed in supporting the planned water landing areas designated for the MA–9 mission, of which 12 ships and 26 aircraft were in the Atlantic planned landing areas, and 11 ships and 18 aircraft were in the Pacific planned landing areas. Additional search aircraft were available as backups to these aircraft on station.

A total of 66 contingency recovery aircraft and associated personnel were on alert status at staging bases around the world to provide support in the event a landing should occur at any place along the ground track. These aircraft were equipped to locate the spacecraft and to provide emergency on-scene assistance if required. A typical support unit at a stag-




(a) Atlantic Ocean




(b) Pacific Ocean

FIGURE 16–4.—MA–9 planned landing areas.

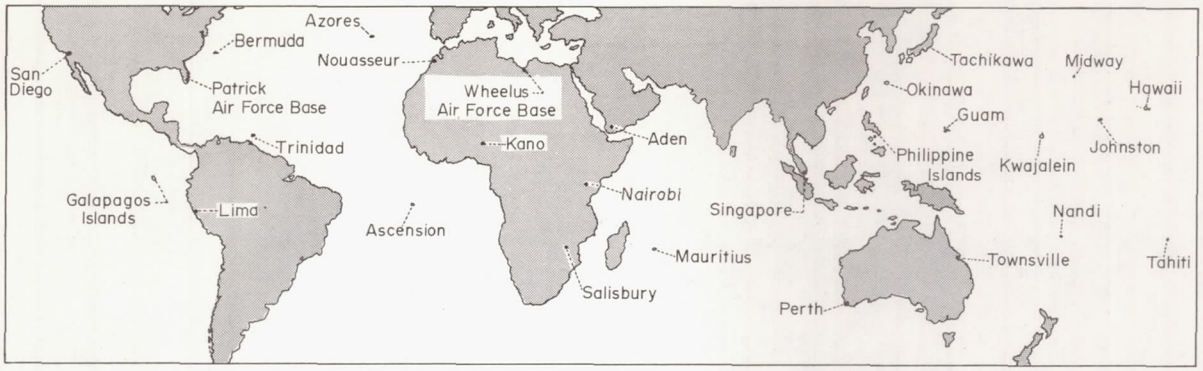



FIGURE 16–5.—MA–9 staging locations for contingency recovery.

ing base consisted of 2 or 3 long-range aircraft with pararescue personnel. The location of contingency recovery units for the MA–9 mission is shown in figure 16–5. All recovery forces, including those in the planned landing area and those supporting contingency landings, were linked by communications with the Recovery Control Center located within the Mercury Control Center at Cape Canaveral.

The location and retrieval of Astronaut Cooper and his spacecraft were straight forward. The spacecraft of the MA–9 mission landed approximately 4½ miles from the recovery aircraft carrier, the *USS Kearsarge*, positioned in the center of Area 22–1. The *USS Kearsarge* had radar contact with the decending spacecraft, and carrier personnel visually sighted the spacecraft as it descended on its main parachute.

Helicopters launched from the carrier prior to spacecraft landing were in excellent position to deploy swimmers who immediately installed the auxiliary flotation collar around the spacecraft. As the carrier approached the spacecraft a motor whaleboat carried a retrieving line to the spacecraft (fig. 16–6). The spacecraft was lifted clear of the water and placed on the carrier deck. The explosive-actuated hatch was then released, and medical personnel began their initial examination of the astronaut.

Following a debriefing and rest period aboard the carrier, the astronaut and his spacecraft were airlifted to Cape Canaveral from Honolulu, Hawaii.



FIGURE 16–6.—Motor whale boat carrying retrieving line to MA–9 spacecraft.

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# 17. ASTRONAUT PERFORMANCE

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## Summary

As flight experience was gained, confidence in the Mercury mission and particularly in the pilot's capabilities increased, which resulted in the pilot playing an increased role in establishing the configuration and in the operation of the spacecraft. As a result (1) improvements were made in preparing the crews for flight, (2) ground-flight coordination was improved, (3) mission rules became more definite, (4) more functions were delegated to the pilot, (5) many systems modifications were made to increase the pilot's systems management capabilities, (6) operating procedures were simplified, (7) flight activities became more flexible, (8) inflight activity priorities were more clearly defined, and (9) pilot workload became better distributed. The benefits of this experience were manifested during the MA–9 mission where the success of the flight was directly attributable to the performance of the pilot.

Mercury flight experience has shown that man's performance in a spacecraft environment is very similar to his performance in an aircraft environment. This fact will enable manned spacecraft designers to utilize several decades of aircraft design and operational experience in the formulation of man-machine relationships for Gemini and Apollo.

Overall results of the Mercury program verify that the pilot, given adequate controls and displays, and sufficient monitoring instrumentation, is a reliable and flexible system of the entire spacecraft and launch vehicle and enhances the success of the mission. In addition, with the proper equipment, he can greatly benefit the experimental effort.

## Introduction

This paper is the summary report on the pilot's ability to operate the Mercury space vehicle and to accomplish experiments as well as make scientific observations. The main topics to be discussed are attitude control of the vehicle and overall management of spacecraft systems because of their importance during Mercury and future space missions, and because it generally in these areas that the most objective and valid data were obtained. The results obtained from each Mercury flight are summarized with particular elaboration upon the MA–9 results since the results of prior flights have been reported in references 1 to 5. Topics are discussed chronologically with examples from each flight when applicable. This approach should illustrate the trend in operational philosophy throughout the program concerning the increased role of the pilot.

## Attitude Determination

Throughout the program a great deal of effort was applied toward investigating the relative value of the Mercury spacecraft's controls and displays for various maneuvers and for vehicle orientation. The results of these investigations, as well as brief description of the different controls and displays, are summarized. Figure 17–1 illustrates the display and control systems that were available in the spacecraft.

The attitude displays available in the Mercury spacecraft were a centerline window, a periscope, and an attitude and attitude-rate indicating instrument (fig. 17–1). The centerline window, located directly in front and almost level with the pilot's head, was trapezoidal

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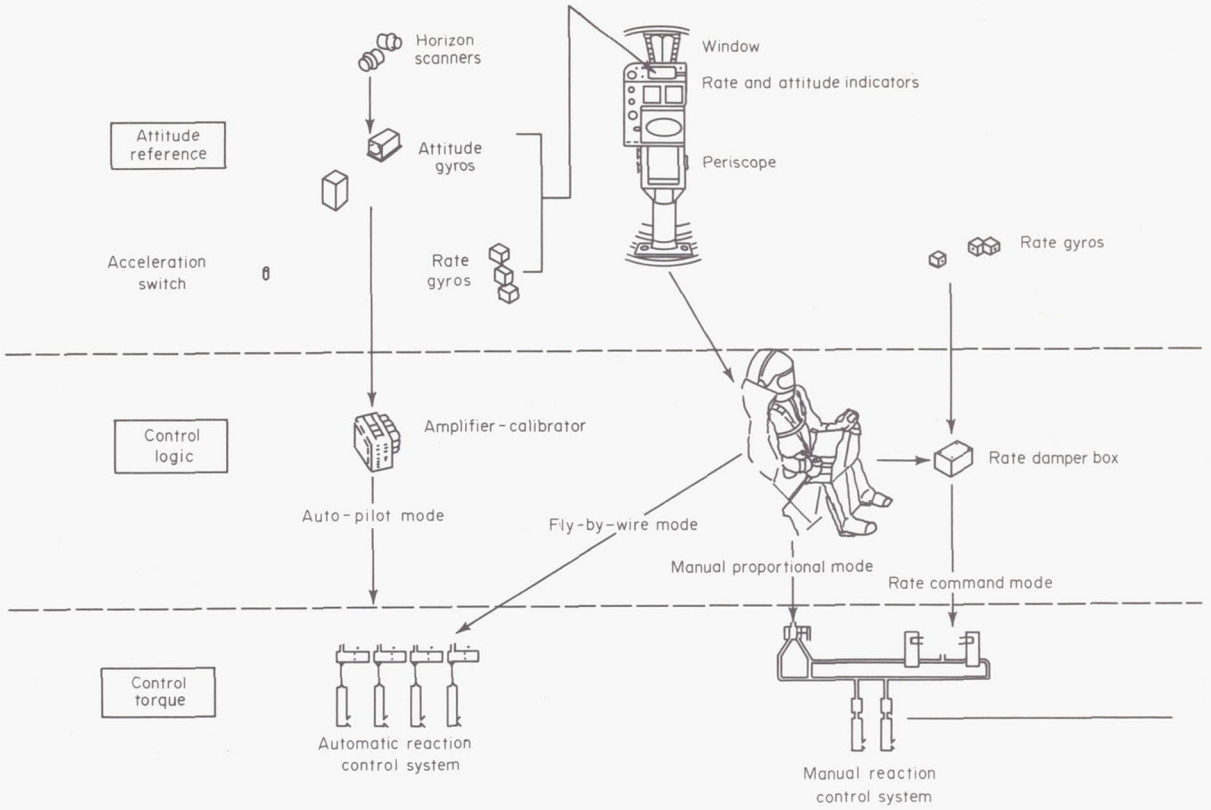



FIGURE 17–1.—Mercury spacecraft display and control systems.

in shape. The viewing limits, with the head restrained, were 33° vertically, 22° laterally at the bottom, and 54° laterally at the top. The periscope, located at the bottom of the center instrument console, was oriented to the earth's nadir when the spacecraft was at a pitch attitude of −14°. The field of view through the periscope was 172°. The attitude and attitude-rate indicating instrument, located at the top of the center instrument console, consisted of six needles, one for each attitude, and one dial which displayed attitude rates. (See fig. 17–2.)

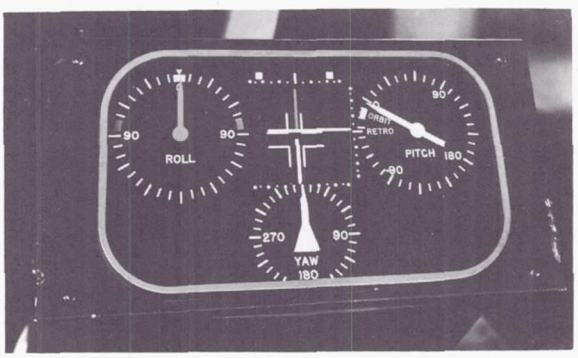



FIGURE 17–2.—Mercury rate and attitude indicators.

The attitude indicators were referenced to the gyros which, in turn, were slaved to the horizon scanners during normal operation.

The relative value of each display system was dependent upon the task to be accomplished. Generally, the window and periscope were both adequate for spacecraft orientation during daylight conditions, whereas only the window was an adequate external display system under reduced lighting conditions. For example, the periscope was the best display for acquisition of the earth horizon and for realinement of the gyros to the true earth-referenced spacecraft attitudes because of its wide field of view. However, in obtaining this wide field of view it was necessary to reduce the image, which resulted in a high attenuation of available light and caused the periscope to be ineffective during the night period. The periscope was removed for the MA–9 flight.

The attitude indicators were used primarily during those periods when the pilot's attention was required in the cockpit, when external references were lacking, and when establishing proper rates and attitudes prior to engaging the

automatic system. The indicators were also preferred for controlling the spacecraft attitude during the firing of the retrorockets because the pilots had been trained much more thoroughly in this method than in using an external visual-display system. Although the attitude indicator system provided good references for such operations as those described above, they also had several shortcomings. Attitude maneuvers beyond a very narrow operating corridor had a great effect upon the accuracy of the system. This problem was reduced as a result of modifications to the later Mercury spacecraft attitude-control systems; however, because of the basic characteristics of the gyros and of the attitude repeater stop limits, it remained a nonversatile system.

In summary, the window was the most versatile and reliable of the three display systems. The periscope disadvantages outweighed its advantages, and the attitude and attitude-rate indicators were a good display system within rather narrow operating limits.

#### Controls

The Mercury spacecraft had four basic attitude-control modes which could be used singly or in various combinations. These control modes were: automatic stabilization and control system (ASCS), manual proportional (MP), fly-by-wire (FBW), and rate stabilization control system (RSCS). Each of these modes was used and evaluated extensively throughout the early Mercury flights, and as a result, their relative value and efficiency for various attitude-control maneuvers became evident.

The ASCS was capable of controlling spacecraft attitude and rates, or both, in all three axes by using information from the attitude and rate gyros. Four automatic modes of operation were available: a reentry mode, an orientation mode, a retrograde attitude hold mode, and an orbit mode. The reentry mode positioned the spacecraft to the proper reentry attitude, inserted the roll rate, and damped the reentry oscillations. The orientation mode was designed to position the spacecraft to any specifically commanded attitude to within $\pm 1°$. The retrograde attitude hold mode utilized the high torque thrusters to maintain the spacecraft to within $\pm 1°$ and $\pm \frac{1}{2}°$/sec of retrofire attitude. The orbit mode was designed to control the spacecraft at the retrofire attitude to within approximately $\pm 8°$. The purpose of the first three control modes is self-explanatory, and their relative value compared with the manual control system is discussed in a subsequent section of this paper. The orbit mode of operation, however, requires a brief discussion at this point. This mode was designed to control the spacecraft within rather broad limits for long periods of time and with economical fuel usage. While in orbit mode, the pilot could devote his attention to other systems, perform experiments, make observations, or relax. During the MA–9 flight this mode was used extensively for conducting various experiments. In addition, the MA–9 pilot utilized a modified orbit mode of operation by manually positioning the Y–Z plane of the spacecraft parallel to the ecliptic plane and then manually realining the attitude gyros to this new reference plane. This action resulted in automatic control of the spacecraft in the desired plane and allowed the pilot to complete the dim-light photographic experiment, the results of which are reported in paper 12.

Of the three manual control systems, FBW proved to be the most versatile. In the initial design, the 1-pound thrusters were actuated at approximately 25 percent of full control-stick travel, whereas the 24-pound thrusters were actuated at approximately 75 percent of full control-stick travel. In order to prevent inadvertent actuation of the high thrusters, a modification was made on the later spacecraft by which the pilot could, by throwing a switch, lock out the high thrusters. Generally, the pilots preferred this control mode during orbit because precise attitude maneuvers and control, or both, could be accomplished with minimum fuel usage.

The MP system was not used extensively during the Mercury flights except in the MA–9 mission. Earlier mission results indicated that neither fine attitude control nor fuel economy could be obtained with this system during orbit because of the minimum thrust levels that could be obtained and the rather long thrust-response lag characteristics that existed in this system. During the MA–9 mission the pilot demonstrated that by making very rapid hand-controller motions, the MP system would produce thrust impulses of a much lower level than

expected. Results of this mission indicated that the pilot was able to exercise precise attitude control with fuel consumption rates similar to those of the FBW 1-pound thrusters.

The RSCS was used primarily for the reentry phase of the flight. It was normally not used for orbital maneuvers because fine attitude control was difficult to maintain and required an excessive amount of control fuel. The RSCS was removed from the spacecraft for the MA–9 flight.

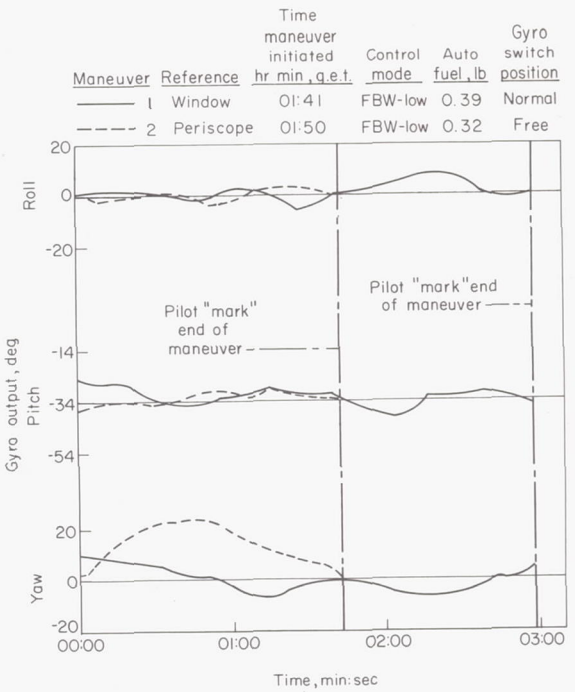
All the various manual control systems were controlled by the pilot by using the three-axis hand controller. This proved to be an adequate controller for manipulation of the manual control systems.

### Yaw Determination

Throughout the Mercury program, investigations were made to determine the pilots' abilities to orient the spacecraft in yaw by use of external reference information. Although pitch and roll reference was not considered difficult as long as a view of the earth's horizon was available, as expected, yaw determination was more difficult. Inflight information was considered necessary to evaluate how accurately and how long it would require the pilot to orient the vehicle, particularly when good external references were lacking.

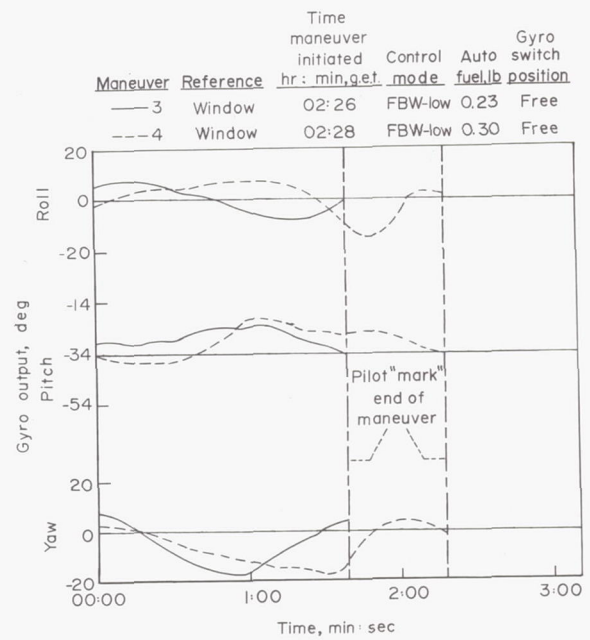
The results from the MA–6 and MA–7 flights indicated that yaw determination during day or moonlit night conditions was not difficult but took more time than did determinations for pitch and roll. Yaw orientation at night with no moon required even more time, and accuracy was somewhat reduced. Both the MA–6 and MA–7 pilots reported that yaw determination by using the window was improved as the vehicle was pitched toward the nadir point. However, since the horizon is not in view to the pilot beyond a pitch-down attitude of approximately 45°, this method makes it difficult to distinguish between yaw and roll errors.

The results of the first two orbital flights suggested that a thorough analysis of yaw determination areas was desirable. A series of yaw maneuvers were planned and accomplished during the MA–8 mission which provided quantitative information on the use of the window and periscope as independent references for determining yaw during both day and night phases of the orbit. (See ref. 5.) The results of these maneuvers are shown in figures 17–3(a) and 17–3(b) and include the attitude variation in all three axes, fuel, time required, and the sole




(a) Day.

FIGURE 17–3.—Yaw maneuvers during MA–8 mission.




(b) Night.

FIGURE 17–3.—Concluded.

reference used. At the termination of each maneuver the pilot "marked" it on the onboard tape recorder.

As can be seen by these figures, the pilot was successful in determining yaw under both day and moonlit night conditions by using the view through the window as a sole reference. Furthermore, these maneuvers were accomplished at a pitch attitude of −34°, which made the horizon available for good pitch and roll reference. The day yaw maneuver in which the view through the periscope was used was completed within the same accuracy and time period as were the yaw maneuvers in which the view through the window was used. The pilot did not attempt a night yaw maneuver using the periscope because he found that it was ineffective even under moonlit night conditions. The pilot stated that he could have alined the spacecraft much more quickly than these maneuvers indicated if urgency had been a more important consideration than the conservation of fuel.

Since the information obtained from the first three orbital missions was quite conclusive, the periscope was removed from the MA–9 spacecraft, and no specific investigation concerning yaw determination was planned for the MA–9 flight. However, it should be noted that in preparing for retrofire, the MA–9 pilot performed a very critical and precise yaw alinement at night by using stars and ground references only.

The MA–9 pilot reported that yaw determination in daylight was quite easy even when only a small portion of the earth horizon was in view (−20° to −25°, pitch attitude). He felt he could accurately aline the spacecraft directly toward or away from the direction of motion over the ground within 1°. At the 90° yaw position he believed his accuracy might be degraded to ±10°. The pilot used several cues to determine yaw attitudes and rates during daylight, such as the "streaming by" of terrain features, and cloud patterns, or both, the convergence point of these flow lines, and the tracking of terrestrial objects or cloud prominences across the window.

The pilot reported that yaw-attitude determination at night was not difficult but it usually required more time. If he was well dark-adapted and the moon was illuminating the earth, he used the motion of terrestrial features and cloud features. Occasionally, lighted cities provided good yaw reference even without moonlight. When these references were not available, he was required to use identifiable stars and constellations. This was more complicated and usually took more time because the restricted field of view through the spacecraft window made identification of the constellations more difficult.

A convenient method of yaw determination was noted by the MA–9 pilot after observing the relative motion of the so-called fireflies seen by all of the pilots of previous orbital missions. These luminous particles, which appeared to emanate from the thrusters, were observed to move outward from the spacecraft and then to recede back along the spacecraft's trajectory in the manner of a contrail, remaining visible for several seconds. The pilot believed that by positioning the spacecraft relative to the motion of these particles, an accurate determination of the 0° yaw position could be achieved.

#### Gyro Realinement

The realinement of the attitude gyros to the spacecraft's attitude was an important function because it directly affected the usability of the entire ASCS and Mercury attitude indicating systems. The two important objectives in accomplishing this maneuver were maximum accuracy of alinement and minimum fuel expenditure. There were several variables which directly affected these objectives, such as the control and display systems used, the external conditions (day-night), the external references available, and the time available. Time was particularly important because the spacecraft could be alined accurately and with low fuel usage even during worst conditions, providing ample time was available to complete the maneuver.

One important systems modification which significantly affected the capability and ease of realining the gyros to the spacecraft attitude was changing the gyro caging position to −34° in pitch. All but the MA–9 spacecraft's gyros caged to the zero position in all three axes. With the spacecraft in this position, the earth horizon was not available through the window. Although the total realinement maneuver was quite complex in the earlier missions, the MA–9 realinement maneuver was relatively simple and

consisted of orienting the spacecraft to the retroattitude position by using the horizon and caging and uncaging the gyros (fig. 17–4). As an example, the amount of fuel used by the MA–9 pilot in accomplishing this maneuver was only approximately 25 percent of the average amount required for the maneuver during the previous Mercury missions.

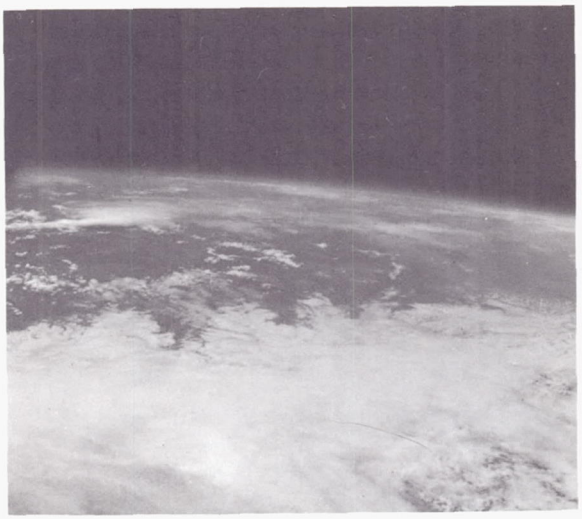


FIGURE 17–4.—Horizon view at retroattitude.

## Attitude Control

### Turnaround Maneuvers

During the suborbital flights and the first oribital flight the spacecraft was turned around to the retroattitude position by the ASCS, whereas the turnaround maneuvers after orbital insertion for the subsequent orbital missions were accomplished manually as shown in table 17–I. The reasons behind this change warrant a brief discussion.

*Table 17–I.—Summary of Turnaround Maneuvers*

| Flight | Control system | Fuel, lb | Time, min:sec |
|---|---|---|---|
| MR–3 | ASCS | 4.0 | 0:30 |
| MR–4 | ASCS | 4.0 | 0:35 |
| MA–6 | ASCS | 5.8 | 0:38 |
| MA–7 | FBW (high and low). | 1.6 | 0:30 |
| MA–8 | FBW-low | 0.3 | 1:10 |
| MA–9 | FBW-low | 0.2 | 1:40 |

ASCS—Automatic stabilization and control system.
FBW—Fly-by-wire.

At the very beginning of Mercury Project, it was not known how well the pilot would be able to function in a space environment. This contributed to the Mercury spacecraft being designed so that most of the inflight functions would be automatic with the man being used as a backup system. As flight experience was gained, confidence was increased in the spacecraft, mission operations, and particularly in the man's capabilities. As a result the pilot was permitted more latitude and given more responsibilities as far as inflight activities, such as the turnaround maneuver, were concerned. A second important factor was that fuel conservation became more important during the longer duration missions. Early flight results indicated that an automatic turnaround maneuver would require between 4 and 6 pounds of control fuel. Results on the Mercury procedures trainers, which simulated quite accurately fuel usages for the various control modes, indicated that the pilot could, after practice, perform the maneuver within the same time period required by the ASCS and with a significant savings in fuel.

On this basis, it was decided that the MA–7 pilot would perform the turnaround maneuver, by using FBW, and complete it within approximately the same time normally required by the ASCS. As can be seen by table 17–I, the MA–7 turnaround required only 1.6 pounds of fuel as compared with the 5.8 pounds of fuel required for the MA–6 automatic turnaround. This fuel conservation verified that subsequent flight turnarounds should be conducted manually.

During the MA–8 flight it was planned that if the flight were proceeding smoothly, the turnaround maneuver would be executed at a leisurely pace at a yaw rate of 3°/sec to 4°/sec with the pilot relying solely on the rate and attitude indicators and using only the FBW 1-pound thrusters to conserve fuel. A secondary objective was to confirm that the pilot could perform the maneuver as precisely in a space-flight environment as he could in trainers on the ground.

The pilot performed the maneuver identically as it had been practiced on the procedures trainer. Figure 17–5 shows the flight gyro attitudes with a background envelope of five turnaround maneuvers accomplished on the

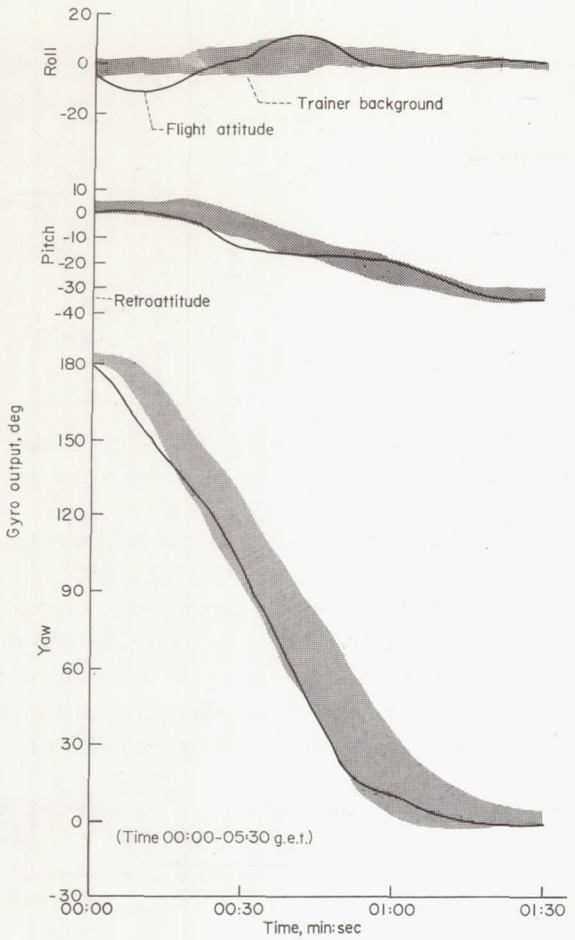



FIGURE 17–5.—Turnaround maneuver, MA–8 mission.

procedures trainers. The pilot executed the maneuver smoothly and with precision, using 0.3 pound of control fuel, which is less than 10 percent of the control fuel normally required by ASCS. As a result of this flight it was clearly established that a leisurely executed manual turnaround, providing the flight was proceeding smoothly, was the most efficient maneuver.

The MA–9 pilot accomplished the turnaround maneuver in a manner similar to that of the MA–8 pilot except that it was not intended to be completed in as precise a fashion as the MA–8 maneuver. He used FBW-low to conserve fuel, but he elected to observe and photograph the launch vehicle rather than position the vehicle directly to the proper retroattitude position. The pilot had been informed that he had a good insertion, that all systems were functioning properly, and therefore that it was not imperative for the spacecraft to be pitched down to retroattitude. The MA–9 turnaround maneuver required only 0.2 pound of control fuel.

### Retrofire

Control of the spacecraft attitude during the firing of the retrorockets was perhaps the most critical and exacting function of either the pilot or the ASCS. Therefore, a great deal of the astronaut's attitude control training on the various fixed and dynamic trainers was devoted to the determination of the relative value of the different control-display configurations and in perfecting the pilot's capability to use these various configurations effectively in accomplishing this maneuver.

The summary of the planned and actual control-display systems used for controlling the spacecraft during the retrofire maneuver of the manned Mercury flights and resultant fuel usages is shown in table 17–II. Of particular note is the fact that only one (MA–8) of the four orbital flight retrofire events was accomplished as planned. The amount of fuel used agrees quite well with the trainer results; that is, in terms of fuel savings there are no significant advantages in selecting any particular control mode.

During the orbital flights it was planned to use the ASCS to control the spacecraft during the retrofire event because it was designed to maintain attitude within very tight limits of $\pm 1°$ and because a manual retrofire did not represent a significant saving in fuel. However, because of systems failures or anomalies affecting the ASCS only the retrofire maneuver of the third orbital flight (MA–8) was accomplished solely by the ASCS.

The MA–6 pilot decided to backup the ASCS by using the MP control system. With this particular set of control modes 11.6 pounds of control fuel were used during the maneuver.

Because of a problem with the ASCS, the MA–7 pilot controlled the spacecraft during retrofire by using both FBW and MP, again resulting in a rather high fuel usage. Because of an error in the pitch indicator the pilot was required to cross-check between the view out the window and his instruments.

The MA–8 spacecraft was controlled by the ASCS during the retrofire event within $\pm 1°$ in

*Table 17–II.—Summary of Retrofire Maneuvers*

| Flight | Control system | | Display | Fuel, lb | Landing error, nautical miles |
|---|---|---|---|---|---|
| | Planned | Actual | | | |
| MR–3 | MP | MP | Instruments | 4. | |
| MR–4 | MP | MP | Instruments | 3. 6 | |
| MA–6 | ASCS | [1] ASCS, MP | Instruments | 11. 6 | −40 |
| MA–7 | ASCS | [1] FBW, MP | Instruments and window | 7. 0 | +250 |
| MA–8 | ASCS | ASCS | | 3. 8 | −4 |
| MA–9 | ASCS | MP | Instruments and window | 3. 2 | −1 |

[1] Double authority
MP—Manual proportional
ASCS—Automatic stabilization and control system
FBW—Fly-by-wire

all axes. The pilot had selected MP as a backup but it was not required.

As a result of the loss of ASCS power, the MA–9 pilot was required to initiate the retrofire event manually and to control the spacecraft during retrofire by using the rate gyro indicators (the attitude indicators were non-operational) and the view of the earth through the window as rate and attitude references, respectively. The pilot, realizing that he would be conducting the retrofire maneuver shortly after sunrise of the final daylight phase, oriented and maintained the spacecraft very close to the proper retroattitude throughout the last night period by using stars and clouds as references. The pilot was well prepared for retrofire, having completed well in advance the storage and preretrosequence checklists.

During the retrofire maneuver, the pilot used MP and cross-checked between his rate indicators and the view through the window. Because of a high contrast between the relative brightness of his interior and exterior references, the pilot experienced difficulty in adapting his vision while shifting from one reference to the other. Consequently, he had to shade his eyes with his left hand when attempting to view his rate indicators. In spite of this problem and the fact that he did not have the opportunity to practice retrofire maneuvers with this combination of attitude references, except much earlier in his training program on the air-lubricated free-attitude (ALFA) trainer, the pilot was able to maintain excellent control of his spacecraft with this combination of attitude references, as evidenced by the nominal reentry trajectory and accuracy in landing position.

Figure 17–6 shows the spacecraft's attitude rates and attitudes, which were calculated from an integration of the spacecraft rates during the retrofire period. The calculated attitudes and the initial attitude of the spacecraft at the

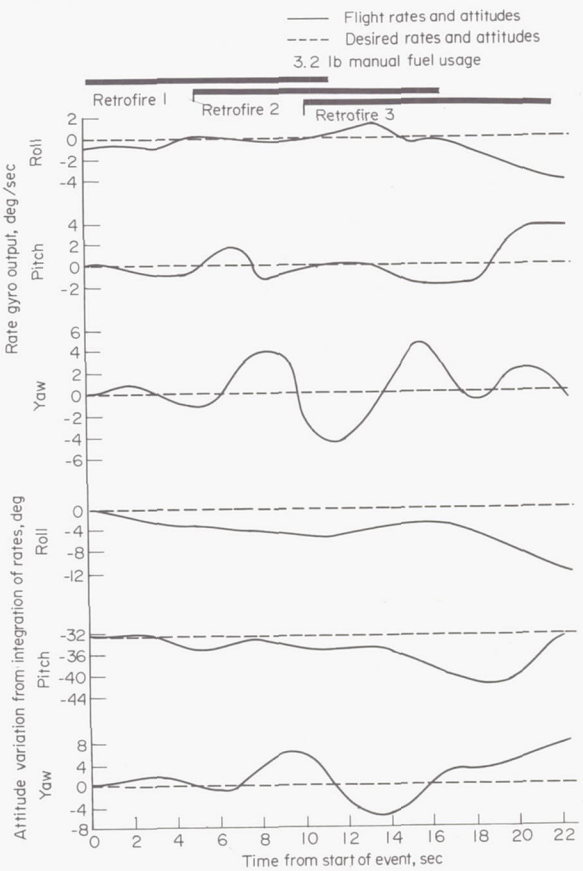



FIGURE 17–6.—MA–9 retrofire maneuver.

beginning of the retrofire were further verified by reentry trajectory computations. The pilot controlled rates extremely well particularly in pitch which is the most critical axis. Rate control was maintained within ±2°/sec in pitch and roll and within ±5°/ sec in yaw throughout the first 19 seconds of the 22-second retrofire period. A maximum misalinement torque of approximately 40 to 50 foot-pounds appears to have occurred in left yaw when the number two retrorocket fired. This value represents approximately 40 percent of the MP control capability.

The pilot maintained good control of spacecraft attitudes, with a maximum deviation of −12° in roll at the completion of the maneuver. Deviations in pitch and yaw attitude were negligible as far as the reentry trajectory and landing accuracy are concerned. The maximum pitch deviation was 9°, which occurred very late in the retrofire period; and the maximum yaw attitude deviation was 5°. The pilot purposely maintained the pitch attitude at the nominal −32° position or slightly lower, a direction of deviation which least affects the reentry trajectory.

### Reentry

During the reentry the ASCS or the pilot, by means of one of the manual control modes, was required to initiate and maintain a roll rate of approximately 10°/sec and to damp the oscillations in the pitch and yaw axes. Since the frequency and damping of the oscillations varies considerably during the reentry phase, with frequency increasing until maximum dynamic pressure, and damping decreasing after the maximum dynamic-pressure period, the control task requires a considerable amount of pilot skill and technique.

The preferred control systems for this task were either the auxiliary damping (ASCS) or the rate command mode. Rate command, although highly effective in controlling the oscillations, usually consumed a large amount of fuel, as can be seen in the case of the MA–8 reentry shown in table 17–III. The MP control mode had a significant response lag and tail-off in thrust, which made it very difficult to damp effectively. The FBW was not completely adequate for effective control because it was limited to the selection of two discrete thrust levels.

All of the manned Mercury flight reentries except MR–3 were planned to be controlled by the auxiliary damping or rate command control modes. Furthermore, these two control modes were used entirely or in part for each Mercury flight reentry with the exception of the MA–9 reentry. The rate command system had been removed from the MA–9 spacecraft and the auxiliary damping system was inoperative because of the loss of ASCS power.

The MA–9 pilot decided to control the reentry by using FBW, but when he checked the system just prior to 0.05g, he was not satisfied with the way it was operating and elected to use both MP and FBW. During the early portion of the reentry he was able to damp the small and rather slow oscillations by using the FBW 1-pound thrusters and the MP control

*Table 17–III.—Reentry Control*

| Mission | Control mode | | Fuel, lb |
|---|---|---|---|
| | Planned | Actual | |
| MR–3 | MP | MP, switched to Aux. damp. | 6.5 |
| MR–4 | RSCS | RSCS | 6.0 |
| MA–6 | Aux. damp. | (MP and FBW)[1] switched to Aux. damp. | 8.6 |
| MA–7 | Aux. damp. | Aux. damp. | 4.6 to fuel depletion |
| MA–8 | RSCS | RSCS | 10.0 |
| MA–9 | Aux. damp. | (FBW and MP)[1] | 5.2 |

[1] Dual authority
MP—Manual proportional
RSCS—Rate stabilization and command system
Aux. damp.—Auxiliary damping part of automatic (ASCS) system
FBW—Fly-by-wire

mode. At approximately 1 minute and 30 seconds prior to peak reentry deceleration, the pilot inadvertently actuated the FBW-high yaw thruster. This actuation resulted in almost 49 pounds of control thrust and added to the amplitude of the oscillations. However, the pilot maintained positive control of the oscillations through drogue parachute deployment. The pilot had no other difficulties in controlling the reentry oscillations except during maximum deceleration for a brief period in which he was unable to manipulate the control handle properly because the g-forces pulled his arm away from the control handle and into a trough on the arm rest.

The maximum frequency of oscillations occurred at peak deceleration with a period on the order of 0.9 second. Maximum rates were approximately $\pm 15°$/sec with a maximum amplitude of approximately $\pm 10°$ in pitch and yaw which occurred after peak deceleration. The pilot reported that he believed he needed dual-authority control to be effective after the peak deceleration point.

## Systems Management

As flight experience was gained and as the successive flights increased in length and complexity, it was necessary to make many modifications and improvements in the controls, displays, and monitoring instrumentation so that the pilot could more effectively manage and assess the status of the spacecraft systems. Increased onboard monitoring capability was particularly important during the MA–9 flight because of the long time periods during which the spacecraft was not within communication contact with the various ground stations. A second advantage of onboard monitoring instrumentation was that it was often more reliable than telemetered data, and, if discrepancies did occur between ground and flight information, the actual status could be better determined with the onboard instrumentation. Finally, as mission duration increased the management of consumables, such as fuel and electrical power, became more critical.

Figure 17–7, which compares the MR–3 and MA–9 spacecraft instrument panels, illustrates the numerous changes in the Mercury panel configuration. These changes primarily resulted from the increased knowledge about the spacecraft systems and their operations as well as the mission requirements. One of the major modifications was to the attitude control system and its controls in order to maximize the capabilities of the system and also to simplify the control system management requirement.

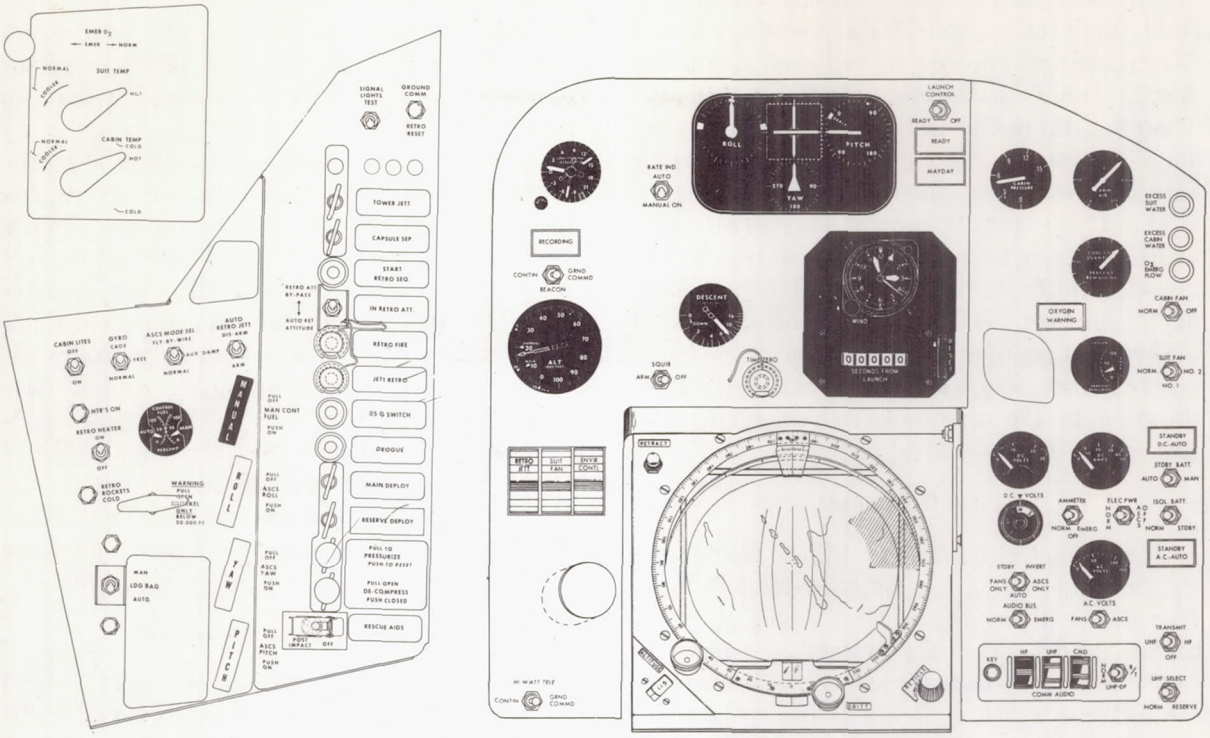
### Control-Mode Switching

A major pilot function during all of the Mercury missions, but particularly during the MA–9 flight, was control-mode usage and switching which had a direct effect upon control-fuel expenditure and the success of the entire mission. Table 17–IV shows control-mode usage and switching during the MA–9 flight. In general, the control system was used almost exactly as planned until the 0.05g relay prematurely latched in and the ASCS power was subsequently lost. After this point, the pilot used FBW and MP, or both, since these were the only available systems.

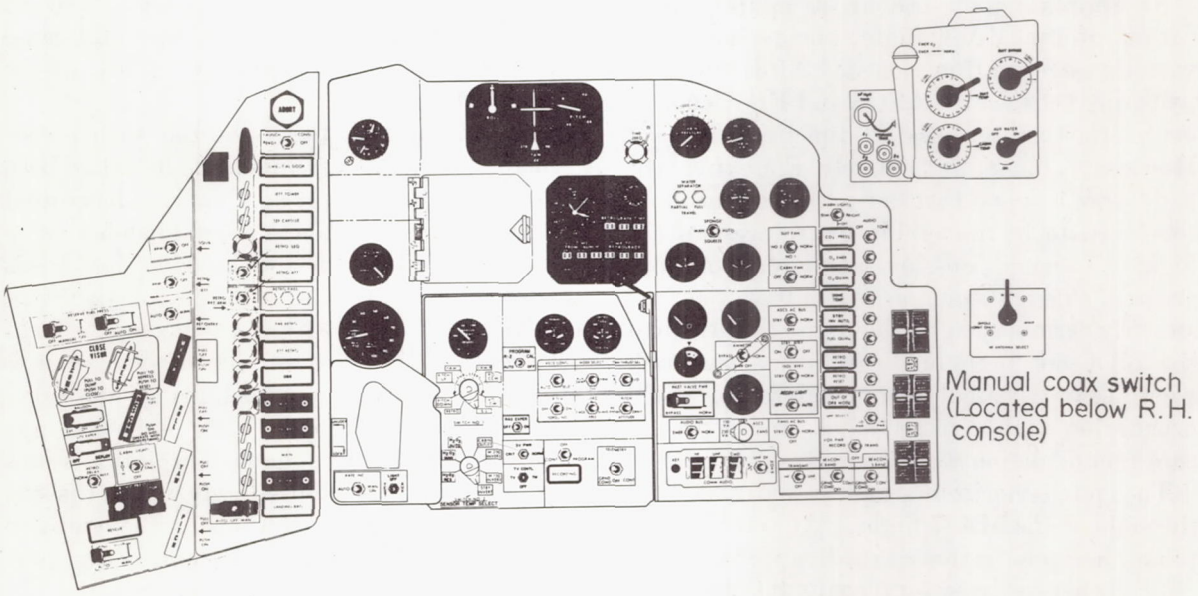
The pilot was very successful in switching from the manual control modes to the ASCS. The orientation high-thruster mode was never

*Table 17–IV.—MA–9 Control Mode Usage*

| Control mode configuration | Percentage time used in rank order | Maximum time used at any one time, hr:min | Frequency used |
|---|---|---|---|
| Drift | 43 | 13:01 | 2 |
| Drift and MP | 26 | 8:44 | 1 |
| ASCS orbit | 13 | 1:20 | 7 |
| Drift and FBW-low | 13 | 3:11 | 1 |
| FBW-low (gyros uncaged) | 2 | 0:11 | 8 |
| ASCS reentry | 2 | 0:37 | 1 |
| MP (gyros uncaged) | 1 | 0:04 | 5 |




(a) MR–3 configuration.




(b) MA–9 configuration.

FIGURE 17–7.—Spacecraft instrument panels.

inadvertently actuated throughout the entire flight. The maximum excursions, during the eight times the spacecraft was manually alined to retroattitude and control switched over to the ASCS, were 5° in attitude and ±½°/sec in rate. The pilot did not at any time inadvertently use double authority during the mission. Double authority was used purposely for the reentry.

The MA–9 pilot's success in control mode utilization can be attributed primarily to two areas: simplification of the control mode switching operations, which reduced the chances of inadvertent use of orientation mode or inadvertent dual authority, and a very thorough understanding of the operational characteristics of the entire attitude-control system.

#### Pilot Reliability

Throughout the Mercury flights there were several minor and a few major systems failures. In order to illustrate the value of the pilot as a backup and/or primary system indispensable to the Mercury space flights, a brief review of the failures which occurred in the spacecraft's attitude-control system during the four orbital flights and the effect that these failures would have had on mission success had the spacecraft been unmanned is warranted.

At approximately 1 hour 30 minutes after lift-off of the MA–6 flight, the 1-pound left yaw thruster malfunctioned. After repeated switching between the ASCS and FBW control modes, the thruster began to function properly. However, almost immediately thereafter the right yaw 1-pound thruster malfunctioned and continued to be inoperable for the rest of the flight. Although mission safety was not jeopardized, this malfunction would have required an early termination of the flight because, had the pilot not been on board, the spacecraft would have repeatedly dropped into the ASCS orientation high-thruster mode, and a premature fuel depletion would have resulted.

The pitch horizon scanner malfunctioned throughout the MA–7 flight. At retrofire, the pitch horizon scanner read approximately −16°, whereas trajectory computations based on radar tracking data yielded a pitch attitude of −36.5°. This discrepancy was verified by the pilot who reported that the ASCS orientation mode caused the vehicle to pitch down below the −34° position to such an extent that the earth's horizon was no longer visible through the window. As a result the pilot had to place the attitude permission switch to the "bypass" position and initiate and control the retrofire event manually. Without the pilot the retrofire could not have been initiated from the proper attitude.

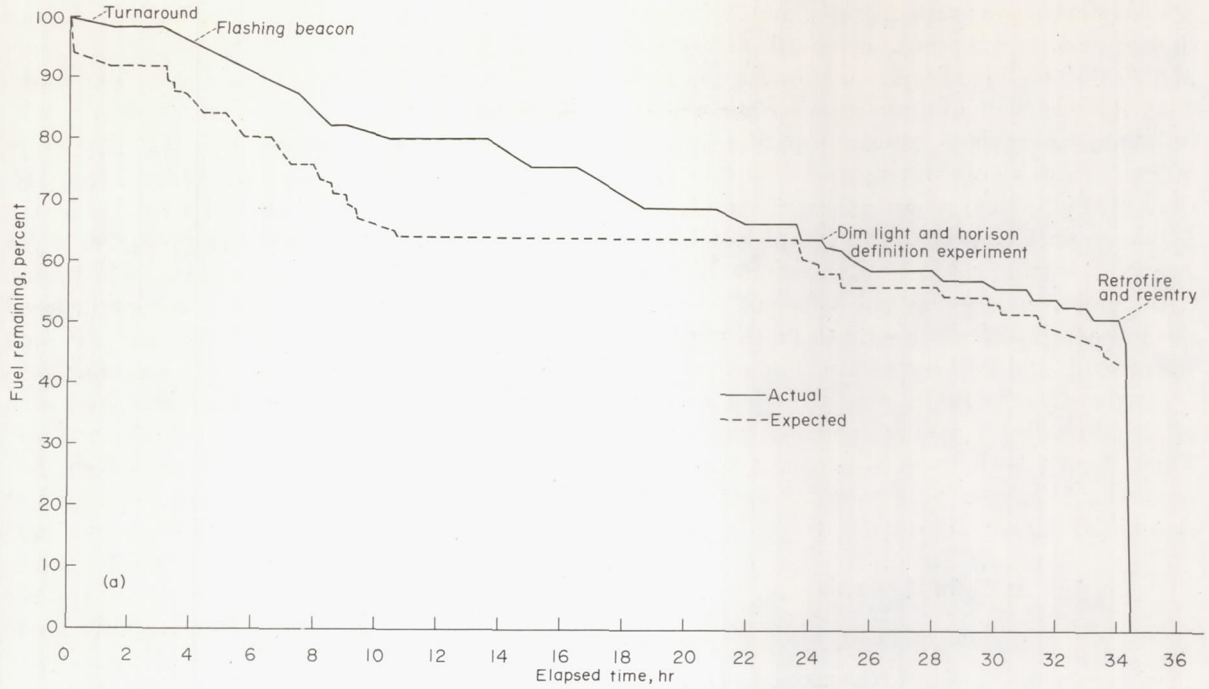
During the MA–9 flight, the amplifier calibrator locked into the 0.05g configuration, which resulted in putting the ASCS into the reentry mode of operation. Shortly thereafter, all ASCS power was lost, and the pilot was required to perform manually all subsequent functions, such as retrofire initiation, retrofire attitude control, and damping of reentry rate oscillations.

In summary, without the man, only the MA–8 flight would have progressed normally; the MA–6 mission would have had to be terminated early; and the MA–9 spacecraft would not have reentered successfully.

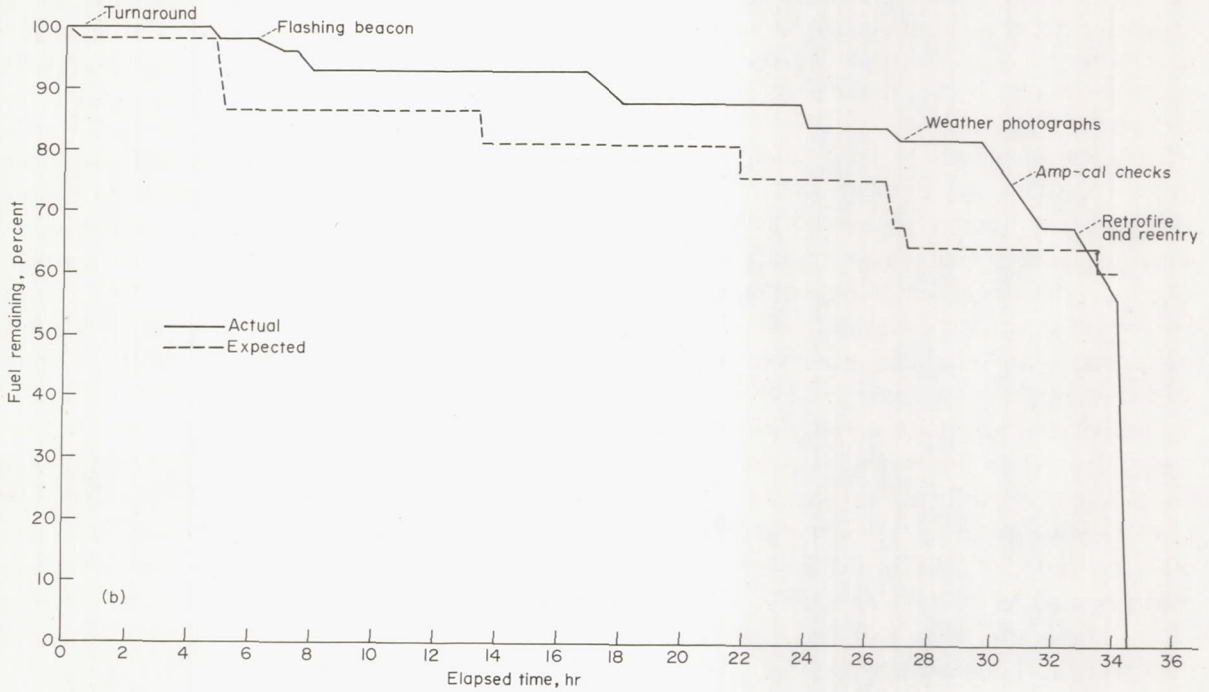
#### Management of Consumables

An important function of the pilot was to monitor and conserve to the extent possible the various consumables, including attitude-control fuel, electrical power, oxygen, water, and the onboard recorder tape. The first two items were extremely critical to the success of the mission since mismanagement or a malfunction affecting either of these quantities could cause an early mission termination or a loss of the spacecraft.

Attitude-control fuel was the prime consumable quantity over which the pilot had both monitoring and control capability. The normal premission procedure was to establish both predicted and minimum fuel-consumption levels that were expected and required for a successful mission. After lift-off, the management of the control fuel to meet the mission requirements was the sole responsibility of the pilot. It was found that for both the Redstone missions and the first two manned orbital missions the fuel quantities required were within the system capabilities; however, during the later two missions the longer duration required that particular attention be paid to this parameter. In most cases, particularly during MA–9, the pilot demonstrated an ability to perform the required maneuvers by using less than the expected amount of fuel and to stay well below the predicted and minimum fuel consumption levels as illustrated in figures 17–8(a) and 17–8(b).




(a) Automatic system.




(b) Manual system.

FIGURE 17–8.—$H_2O_2$ fuel usage.

Electrical power capacity was ample for the shorter duration missions, such as the MA–6 and MA–7 flights. However, monitoring of this quantity was still of importance since a malfunction, if major, could jeopardize flight safety. It was only during the final two missions that electrical power conservation became a concern with respect to full completion of the mission. During the last two missions the electrical power source was not sufficient to allow the use of all electrical equipment throughout the mission and still have an adequate reserve. Consequently, the flight plan included periods of drifting flight in order to conserve power. Thus, during both these missions, it was very important that the pilot monitor and control closely this consumable quantity.

## Inflight Activities

### Flight Plan

The activities of the pilot on each Mercury mission included requests and requirements from medical, engineering, and scientific areas. In order to obtain the maximum amount of information from each mission, it was necessary to schedule all the activities of the pilot and to assign a priority system in the event of overlap between activities.

The type of activities with which the pilot was involved varied from mission to mission, but generally they included normal systems monitoring and control, spacecraft attitude control, systems checkout, air-ground coordination, medical, and experimental. Activities related to mission reliability such as spacecraft control were given top priority. Second priority activities were those investigations which were intended to improve the spacecraft and its mission capabilities in general. Third priority was given to the experimental and other operational activities that were not directly related to the mission safety. Once all of the flight activities had been determined, they were formulated into a flight plan that was designed to meet all of the objectives of the mission.

The period of weightlessness of the manned Mercury-Redstone flights was too short to allow many activities. The flight plan for these two missions concentrated primarily upon the overall operational requirements, and during the weightless period emphasis was placed upon an evaluation of the various spacecraft attitude-control systems. Starting with the MA–6 mission, all conditions during orbital flight had to be considered. The launch, retrofire, and reentry procedures were similar to those of the Mercury-Redstone missions; however, the orbital period required detailed scheduling. Spacecraft systems checkouts were scheduled following insertion and at the end of each orbital pass. Activities related to mission control and mission-orientated information, such as medical, control-display analyses, and experimental activities, were scheduled so that they would not interfere with basic operational tasks. Results of each mission were analyzed and the knowledge gained was applied to the subsequent missions. The following are the general areas where improvements were made based on the previous mission experience. First, pilots were allowed more time for each specific activity. The first orbital pass was reserved for systems checkout, and time was allowed for the pilot to become orientated to his new environment. More time was allotted for monitoring systems, and the air-to-ground communications were improved and simplified so that they would require a minimum of the pilot's time. Second, the spacecraft systems were analyzed in more detail and the pilots were thoroughly briefed on their characteristics. The spacecraft configuration and activity schedule were also finalized at an earlier date than had been true on previous missions and this allowed the pilot valuable additional time to train and become more familiar with the flight activity schedule.

The sum total of all these improvements was reflected in the MA–9 mission plan. At only one period did the pilot feel rushed; however, even in this case he was able to complete the scheduled activity. Two additional factors which contributed greatly to the improved flight activity schedule of the MA–9 mission were that activities were scheduled at any of several different points in the mission so that the pilot could conduct the activity at the most convenient time and that the increased mission duration allowed a reduction in the frequency of activities.

### Communications

Air-to-ground communications procedures were continually being improved throughout the Mercury program in an attempt to determine the best set of procedures which would be simple for the pilot and yet insure proper information flow.

The MA–6 pilot was requested to report a large quantity of information to the various ground stations. Over each ground station, he reported the fuel and oxygen quantities, the control mode, and the general status. In addition, approximately twice during each orbital pass, he was required to report to a ground station all the switch positions and gage readings on the instrument panel. In addition many communication attempts were required to establish contact with each station, primarily because the stations would attempt communications contact prior to the expected acquisition time. These premature attempts resulted in many additional transmissions in an attempt to make two-way communications contact.

Several changes were made in communications procedures prior to the MA–7 flight. The requirement for reporting all the switch and gage readings was deleted and the initial transmission from the ground was not begun until the expected time of acquisition. The MA–8 pilot reported only control mode and status. In addition, many intermediate transmissions were eliminated because the pilot transmitted specific information at given stations, which reduced the number of requests initiated from ground stations. The net effect of all these changes was to decrease the amount of the pilot's time required for this activity and thus permit more time for other activities.

The MA–9 communications procedures represented the application of all the previous experience and included several major improvements. Ground stations did not attempt communications with the spacecraft until after they had received the spacecraft telemetry signals and had evaluated the data. This procedure insured that the spacecraft and ground station were in good communications range. In addition the MA–9 pilot reported only go–no–go status to each station and read out fuel and oxygen quantities once per orbital pass. The sleep period, during which communication silence was maintained, also greatly decreased the total air-to-ground communications. One communications problem that did occur during the MA–9 flight was an interruption due to ground station communications while the pilot was conducting the dim-light experiment.

## Conclusions

Conclusions concerning the performance of the pilot during the Mercury program and the implications for future manned space programs are:

(1) The pilot during Mercury flights was a reliable and flexible part of the system, and therefore enhanced mission success.

(2) The three-axis hand controller proved to be adequate for spacecraft control.

(3) Although the Mercury training equipment was generally adequate, good external displays would have provided valuable additional training.

(4) Spacecraft systems modifications should be finalized as early as possible to permit earlier flight-plan finalization and to allow more time for the pilot to practice the various inflight tasks.

(5) There was no significant effect upon pilot's operating capabilities resulting from his being subjected to the space environment for up to 34 hours.

(6) Throughout the Mercury Project there was a trend toward design and operational concepts similar to those for flight-test aircraft. This indicates that the decades of aircraft experience will be very useful in designing systems, selecting and training astronauts, and mission planning.

(7) It is advantageous from a reliability and systems simplicity standpoint to make maximum use of the pilot's capabilities in spacecraft operations. Early design should take manual operation into consideration in order to achieve a most effective and efficient overall system. Those functions that are determined to be beyond man's capability or are of a monotonous or repetitious nature should be designed for automatic operations.

## References


1. Staffs of NASA, Nat. Inst. Health, and Nat. Acad. Sci.: *Proceedings of a Conference on Results of the First U.S. Manned Suborbital Space Flight.* Supt. Doc., U.S. Government Printing Office (Washington, D.C.), June 6, 1961.
2. Staff of NASA Manned Spacecraft Center: *Results of the Second U.S. Manned Suborbital Space Flight, July 21, 1961.* Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
3. Staff of NASA Manned Spacecraft Center: *Results of the First United States Manned Orbital Space Flight, February 20, 1962.* Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
4. Staff of the NASA Manned Spacecraft Center: *Results of the Second United States Manned Orbital Space Flight, May 24, 1962.* NASA SP–6, Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
5. Staff of NASA Manned Spacecraft Center: *Results of the Third United States Manned Orbital Space Flight, October 3, 1962.* NASA SP–12, Supt. Doc., U.S. Government Printing Office (Washington, D.C.), Dec. 1962.

# IV

# MISSION RESULTS

707-056 O—63——20

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# 18. AEROMEDICAL OBSERVATIONS

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## Summary

The results of physiologic measurements and medical studies of Astronaut Cooper made prior to, during, and following his flight as pilot of the spacecraft of the MA–9 mission are presented in this paper. The pilot was in excellent health and in a complete state of mental and physical fitness for his mission on launch morning. The data revealed that all physiologic parameters measured in flight remained within the envelope of normal variability developed for this pilot through extensive monitoring of these same parameters under dynamic circumstances during his participation in training activities as a Mercury astronaut.

Astronaut Cooper withstood the stresses of the flight situation with no evidence of degradation of his functional integrity as a pilot. He slept as part of the planned mission activities during his flight and reported that sleep was subjectively normal. Postflight examination of Astronaut Cooper revealed that he had developed dehydration. He exhibited an orthostatic hypotension accompanied by an accelerated pulse response in the postflight examinations. The pulse and blood pressure responses returned to normal while the pilot was sleeping between 9 hours and 19 hours after landing. A reversal of the ratio between neutrophiles and lymphocytes was noted in the peripheral blood at an examination accomplished 4 days after the mission. This lymphocytosis persisted for 2 weeks and subsided spontaneously by June 14, 1963. With respect to all other studies, the medical status of the pilot was found essentially unchanged between the preflight and postflight examinations.

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## Introduction

This paper presents the specific results of medical studies of Astronaut Cooper's responses during and after his MA–9 mission in the dual context of a detailed report of the final Mercury mission and an effective summary in its own right of the medical findings from Project Mercury. The results of the MA–9 mission are an effective summary of the entire program because every observation which was made on pilots during the earlier missions was repeated and qualitatively reconfirmed in the final flight.

At the same time, the medical-data collection program for the last flight was developed on the foundation of knowledge gained from each of the preceding manned space missions. The suitability and the limitations of the Mercury spacecraft environment to meet the requirements of human physiology were better understood with each succeeding flight. Thus, the final flight was approached with a better understanding of the likelihood of a given physiologic response occurring after exposure to the known stresses of a mission profile than had been previously possible. The opportunity for making valid medical observations during the MA–9 mission was further enhanced by the duration of the mission, as well as by the length of participation of Astronaut Cooper in the Mercury program, which provided an invaluable fund of baseline data prior to his actual flight.

## Preflight Observation

Data were evaluated from very thorough medical studies of the pilot, Astronaut L. Gordon Cooper, Jr., conducted immediately prior to his selection for astronaut training in 1959 and from annual examinations since that

date. Medical examinations were also conducted both before and after six preflight spacecraft checkout tests and a session in the Cape Canaveral procedures trainer, all of which required the pilot to wear the full-pressure space suit. Special examinations to assess the pilot's fitness for flight were conducted 11 and 3 days before launch. The latter examination conducted on May 12, 1963, designated the "Comprehensive Medical Evaluation," was conducted by specialists in internal medicine, ophthalmology, neuropsychiatry, radiology, and aviation medicine. The NASA flight surgeon who had examined the pilot for most of the preflight activities conducted the final preflight medical examination on launch morning. The preflight aeromedical procedures and examination are listed in table 18–I.

*Table 18–I.—Pilot Preflight Activities*

[Selected activities for which medical study or support was performed]

| Date | Activity | Medical study or support |
|---|---|---|
| January 5 | Altitude-chamber spacecraft checkout. | Physical examination before and after<br>Background data (biosensors) |
| March 22–23 | Hangar flight simulation | Physical examination before and after<br>Background data (biosensors)<br>Low residue diet (3 days) and flight food (2 days) |
| April 23 | Flight simulation no. 1 | Physical examination<br>Background data (biosensors)<br>Timed urine collection |
| May 4 | T–10 day physical examination. | Physical examination, 45 minutes |
| May 7 | Mission simulation (procedures trainer). | Physical examination before and after<br>Background data (biosensors)<br>Timed urine collection |
| May 8 | Launch simulation | Physical examination before and after<br>Background data (biosensors)<br>Timed urine collection<br>Begin controlled diet<br>Blood specimen, 50 cc |
| May 10 | Flight simulation no. 3 | Physical examination before and after<br>Timed urine collection<br>Background data (biosensors) |
| May 11 | | Begin low residue diet |
| May 12 | T–2 day physical examination | Comprehensive medical examination, 2½ hours<br>Blood (30 cc) and urine specimen |
| May 14 | Countdown (flight canceled) | Physical examination before and after<br>Timed urine collection<br>Blood specimen, 30 cc |
| May 15 | Flight countdown | Physical examination<br>Aeromedical countdown<br>Awaken 2:51 a.m. e.s.t.<br>Launch 8:40 a.m. e.s.t. |

In addition to examinations by physicians, baseline clinical evaluations included an audiogram, an electrocardiogram, a chest X-ray, and laboratory studies of blood and urine. The results of these evaluations are found in tables 18–II to 18–V. For the 3 months prior to the flight, the pilot continued in excellent health with no significant abnormalities. In the month prior to flight, he maintained his physical fitness by daily distance running and calisthenics.

Close supervision of the pilot's food intake began 7 days before the planned flight with special preparation of a normal balanced diet. In order to reduce the need for defecation during the mission, a low-residue diet was followed for 4 days before the launch (ref. 1). This diet was well tolerated, although the pilot did mention that appetite satisfaction was short-lived following the low-residue meals.

*Table 18–II.—Pertinent Excerpts From Clinical Examination*

| | Preflight, May 15, 1963; 3:55 to 4:11 a m. e.s.t. | Postflight (*U.S.S. Kearsarge*) May 16, 1963, 7:15 to 7:45 p.m. e.s.t. |
|---|---|---|
| Temperature (oral), °F | 97. 4 | 99. 4 |
| Heart rate, beats/min | 76 | 86 |
| Respiration rate, breaths/min | 16 | 16 |
| Blood pressure, left arm, mm Hg | 108/76 supine<br>122/82 standing | 90/80 supine |
| Nude weight (bladder empty), lb | 147 | 139¼ |
| Comments | Alert, cooperative, 2+ erythema at BPMS microphone tape site. | Fatigued and sweating. See text. |

*Table 18–III.—Complete Blood Count*

[All times are in e.s.t.]

| | Sept 4, 1959 | Mar 4, 1963; 1:40 p.m. | May 12, 1963; 5:00 p.m. | May 16, 1963; 8:55 p.m. | May 17, 1963; 9:00 p.m. | May 20, 1963; 11:00 a.m. | May 31, 1963; 3:00 p.m. | June 14, 1963 |
|---|---|---|---|---|---|---|---|---|
| Hematocrit, percent | 46 | 44 | 43 | 49 | 43 | 43 | 43 | 43 |
| Hemoglobin, grams/100 ml | 14. 8 | 14. 3 | 15. 0 | 16. 5 | 14. 0 | 14. 7 | 14. 3 | 14. 2 |
| Red blood cells, millions/mm³ | 5. 09 | ----- | 4. 79 | 4. 80 | 4. 83 | 4. 50 | ----- | ----- |
| Platelets/mm³ | ----- | 284, 000 | 314, 000 | ----- | ----- | 230, 000 | ----- | ----- |
| White blood cells/mm³ | 5, 850 | 6, 800 | 6, 500 | 9, 200 | 5, 650 | 6, 000 | 7, 700 | 5, 100 |
| Differential blood count: | | | | | | | | |
| Neutrophiles, percent | 69 | 50 | 60 | 75 | 49 | 35 | 38 | 49 |
| Lymphocytes, percent | 29 | 46 | 36 | 20 | 42 | 58 | 61 | 47 |
| Monocytes, percent | 1 | 2 | 3 | 5 | 5 | 5 | 1 | 2 |
| Eosinophiles, percent | 0 | 2 | 1 | 0 | 3 | 2 | 0 | 1 |
| Basophiles, percent | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |

*Table 18–IV.—Comparison of Typical Preflight and Postflight Urine Values*

| | Preflight | Postflight |
|---|---|---|
| Date, 1963 | May 12 | May 20 |
| Source | Random sample | Random sample |
| Specific gravity | 1.018 | 1.019 |
| pH | 6.0 | 6.0 |
| Albumen, sugar, acetone, and bile | Negative | Negative |
| Microscopic | Few WBC, no RBC, small amounts of amorphous phosphates and mucus, and one hyaline cast. | One to 2 WBC/HPF, no RBC, no casts, moderate amount of amorphous phosphates. |

*Table 18–V.—Urine Analysis*

| Date | Time | Total volume, cc | Specific gravity | Na, mEq/*l* | K, mEq/*l* | Ca, mEq/*l* | Cl, mEq/*l* | $PO_4$, mg% | Creatinine, mg% | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| Mar. 20, 1963 | 7:30 a.m. to 9:26 a.m. | 184 | 1. 012 | 141 | 55 | 4. 15 | 161 | 26. 7 | 85 | Low residue diet. |
| Mar. 20, 1963 | 9:26 a.m. to 12:59 p.m. | 260 | 1. 013 | 180 | 49 | 16. 3 | 207 | 42. 2 | 110 | |
| Mar. 20, 1963 | 12:59 p.m. to 4:45 p.m. | 420 | 1. 014 | 129 | 40 | 10. 1 | 159 | 56. 6 | 86 | |
| Mar. 20, 1963 | 4:45 p.m. to 9:10 p.m. | 330 | 1. 015 | 125 | 38 | 8. 7 | 111 | 73 | 111 | |
| Mar. 21, 1963 | 9:10 p.m. to 1:00 a.m. | 340 | 1. 012 | 137 | 17 | 7. 5 | 100 | 58. 3 | 102 | |
| Mar. 21, 1963 | 1:00 a.m. to 7:52 a.m. | 830 | 1. 005 | 79 | 14 | 5. 0 | 79 | 31. 4 | 62 | |
| Mar. 21, 1963 | 7:52 a.m. to 12:46 p.m. | 470 | 1. 011 | 143 | 42 | 10. 3 | 174 | 26. 6 | 94 | |
| Mar. 21, 1963 | 12:46 p.m. to 5:28 p.m. | 286 | 1. 017 | 179 | 54 | 16. 85 | 210 | 74. 3 | 125 | |
| Mar. 21, 1963 | 5:28 p.m. to 11:35 p.m. | 600 | 1. 015 | 189 | 41 | 7. 6 | 178 | 48 | 105 | |
| Mar. 22, 1963 | 11:35 p.m. to 3:26 a.m. | 210 | 1. 015 | 239 | 31 | 10. 6 | 163 | 54 | ---- | |
| Mar. 22, 1963 | 3:26 a.m. to 5:36 a.m. | 110 | 1. 018 | 216 | 34 | 25. 5 | 165 | 55 | ---- | |
| Mar. 22, 1963 | 5:36 a.m. to 10:47 a.m. | 255 | 1. 018 | 154 | 38 | 21. 3 | 142 | 54 | 134 | |
| Mar. 22, 1963 | 10:47 a.m. to 6:35 p.m. | 300 | 1. 020 | 116 | 47 | 20. 85 | 86 | 135 | 152 | Before hangar simulated flight. |
| Mar. 23, 1963 | 6:35 p.m. to 1:20 a.m. | 360 | 1. 023 | 131 | 51 | 18. 9 | 119 | 75. 4 | 142 | During hangar simulated flight. |
| Apr. 23, 1963 | 6:00 a.m. to 6:50 a.m. | 32 | ------ | 196 | 58 | 7. 75 | 158 | 146 | 144 | Simulated flight no. 1 (before). |
| Apr. 23, 1963 | 6:50 a.m. to 12:35 p.m. | 394 | 1. 020 | 226 | 85 | 3. 04 | 220 | 70. 8 | 106 | Simulated flight no. 1 (during). |
| Apr. 23, 1963 | 12:35 p.m. to 5:08 p.m. | 122 | 1. 022 | 195 | 51 | 5. 95 | 187 | 68. 6 | 98 | Simulated flight no. 1 (after). |
| Apr. 25, 1963 | Unknown to 11:35 a.m. | 170 | 1. 020 | 192 | 83 | 6. 3 | 212 | 18. 7 | 107 | Simulated flight no. 2 (before). |
| Apr. 25, 1963 | 11:35 a.m. to 4:28 p.m. | 134 | 1. 024 | 242 | 40 | 5. 75 | 226 | 35. 4 | 104 | Simulated flight no. 2 (during). |
| Apr. 25, 1963 | 4:28 p.m. to 5:55 p.m. | 308 | 1. 018 | 250 | 44 | 3. 40 | 234 | 46. 1 | 107 | Simulated flight no. 2 (after). |
| May 7, 1963 | 6:30 a.m. to 8:30 a.m. | 64 | 1. 020 | 115 | 56 | 13. 9 | 198 | 103 | 152 | Procedures trainer (before). |
| May 7, 1963 | 8:30 a.m. to 2:00 p.m. | 480 | 1. 014 | 124 | 60 | 5. 65 | 146 | 63. 6 | 88 | Procedures trainer (during). |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| May 8, 1963 | 9:15 a.m. to 1:40 p.m. | 540 | 1.012 | 137 | 79 | 7.4 | 166 | 41.6 | 74 | Launch simulation (during). |
| May 8, 1963 | 1:40 p.m. to 6:00 p.m. | 360 | 1.012 | 137 | 53 | 3.2 | 125 | 43 | 104 | Launch simulation (after). |
| May 10, 1963 | 7:30 a.m. to 11:45 a.m. | 180 | 1.023 | 148 | 85 | 17.8 | 176 | 45.7 | 130 | Simulated flight no. 3 (before). |
| May 10, 1963 | 11:45 a.m. to 2:00 p.m. | 170 | 1.025 | 198 | 72 | 20.7 | 219 | 76 | 114 | Simulated flight no. 3 (before). |
| May 10, 1963 | 2:00 p.m. to 6:30 p.m. | 320 | 1.023 | 181 | 83 | 13.4 | 201 | 97 | 115 | Simulated flight no. 3 (during). |
| May 10, 1963 | 6:30 p.m. to 10:05 p.m. | 80 | 1.026 | 200 | 71 | 6.9 | 165 | 148 | 139 | Simulated flight no. 3 (after). |
| May 13, 1963 | 6:30 p.m. to 9:00 p.m. | 440 | 1.025 | 177 | 54 | 19.95 | 165 | 128 | 137 | Before canceled flight. |
| May 14, 1963 | 9:00 p.m. to 2:50 a.m. | 225 | 1.024 | 165 | 32 | 10.0 | 107 | 161 | 152 | Before canceled flight. |
| May 14, 1963 | 2:50 a.m. to 7:30 a.m. | 680 | 1.012 | 120 | 49 | 5.6 | 128 | 12.6 | 56 | Collection device—canceled flight. |
| May 14, 1963 | 7:30 a.m. to 12:30 p.m. | 315 | 1.015 | 98 | 50 | 5.85 | 109 | 34 | 104 | After canceled flight. |
| May 15, 1963 | 10:00 p.m. to 2:52 a.m. | 178 | 1.028 | 112 | 34 | 23.4 | 73 | 214 | 162 | Preflight. |
| May 15, 1963 | 2:52 a.m. to 3:55 a.m. | 25 | 1.025 | 98 | 48 | 12.4 | 89 | 185 | 165 | Preflight. |
| May 15, 1963 | 3:55 a.m. to 7:56 a.m. | 177 | ------ | 184 | 68 | 8.25 | 212 | 33.8 | 125 | Preflight (pad) bag no. 1. |
| May 15, 1963 | 7:56 a.m. to 12:29 p.m. | 195 | ------ | 213 | 69 | 14.1 | 236 | 28.4 | 131 | Inflight bag no. 2. |
| May 15, 1963 | 12:29 p.m. to 10:09 p.m. | 314 | ------ | 197 | 56 | 12.6 | 188 | 130 | 154 | Inflight bag no. 3. |
| May 16, 1963 | 10:09 p.m. to 7:15 a.m. | 333 | ------ | 120 | 38 | 17.7 | 128 | 125 | 169 | Inflight bag no. 4. |
| May 16, 1963 | 7:15 a.m. to 1:14 p.m. | 107 | 1.026 | 137 | 41 | 15.6 | 150 | 136 | 170.8 | Collection device. |
| May 16, 1963 | 1:14 p.m. to 9:30 p.m. | 70 | 1.031 | 107 | 96 | 16.4 | 126 | 240 | 177 | 1st voided sample. |
| May 17, 1963 | 9:30 p.m. to 1:05 p.m. | 475 | 1.026 | 41 | 62 | 20.95 | 29 | 149 | 148 | 2d voided sample. |
| May 17, 1963 | 1:05 p.m. to 9:12 p.m. | 315 | 1.020 | 29 | 54 | 24.3 | 59 | 68.5 | 148 | 3d voided sample. |
| May 18, 1963 | 9:12 p.m. to 12:00 p.m. | 605 | 1.023 | 29 | 70 | 17.4 | 41 | 114 | 139 | 4th voided sample. |
| May 20, 1963 | 8:00 a.m. to 10:15 a.m. | ---- | 1.019 | 125 | 92 | 15.2 | 150 | 68 | 110 | 4 days after recovery (physical exam Patrick AFB). |

The results of the final prelaunch examination revealed a healthy pilot who was ready for the mission. Two minor discrepancies were local skin erythema at the biosensor sites and moderate erythema, edema, and tenderness of the skin over the right sacral prominence. He frequently demonstrates a skin reaction around the sensors for 24 to 36 hours after application, despite the use of microporous surgical tape for fastening these sensors. It should be noted that these sensors were in place for 7 hours during the canceled launch on the preceding day. The skin findings over the sacrum are frequently present following prolonged periods of 4 or more hours on his back in the couch.

On the night before the postponed launch of May 14, 1963, the pilot slept well for about 2 hours and then dozed restlessly for another 3½ hours. However, on the night before the successful launch, he slept well for 6 hours. Although he did become sleepy during periods of relative inactivity, such as the period spent in the transfer van, he felt adequately rested on launch morning. At no time was a drug administered to induce sleep.

The sources of detailed preflight physiologic data are outlined in tables 18–VI to 18–IX. These sources include dynamic tests for evaluation of general physical condition, Mercury-Atlas three-orbital pass simulations, and Mercury-Atlas acceleration profiles conducted at the U.S. Naval Aviation Medical Acceleration Laboratory (AMAL) in Johnsville, Pa., and various spacecraft checkout procedures required during the final stages of preparation for flight.

The procedures which were monitored resulted in the largest number of total hours of observation yet available for any one astronaut. This extensive monitoring was possible as a result of his activity as the MA–8 backup pilot and of his participation in three altitude-chamber spacecraft-checkout procedures, including the longest such test conducted at Cape Canaveral.

The pilot-safety monitoring and data-gathering biosensor system for this mission consisted of two sets of electrocardiographic (ECG) leads, the impedance pneumograph, an oral temperature thermistor, and the blood-pressure measuring system (BPMS). The details of operation of the biosensor system have been described in references 1 to 3. Because of the increased duration of the MA–9 flight, a change was made from continuous rectal to intermittent oral body temperature measurement. The basic thermistor was retained. The thermistor and its lead wires remained within the suit. The sensor was attached to the right ear muff inside the helmet where it was readily accessible. The sensor and its location are illustrated in figures 18–1 and 18–2. It thereby provided an

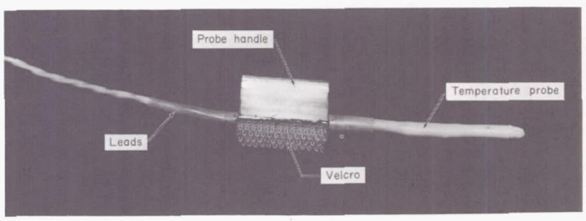



FIGURE 18–1.—Oral temperature probe.

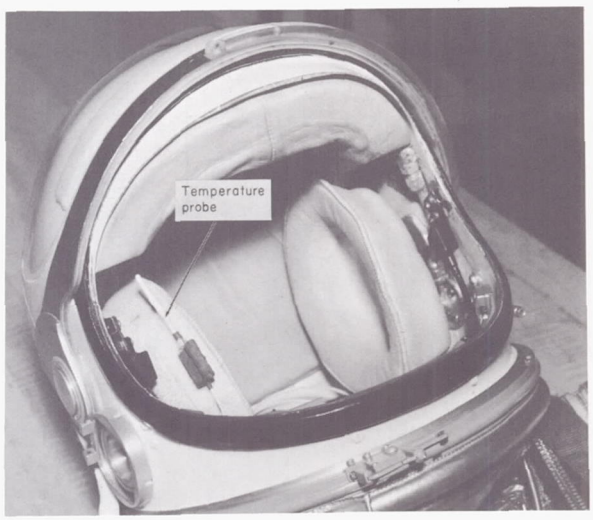



FIGURE 18–2.—Installation of oral temperature probe in helmet.

indication of suit-outlet temperature whenever an oral temperature was not being taken. When oral temperature was desired, the pilot placed the small thermistor under his tongue for about 5 minutes. Preflight body temperatures were all within the normal range. The remainder of the biosensor system was the same as that used for the MA–8 mission (ref. 1).

Preflight biosensor preparation included careful calibration of the system so that accurate, repeatable determinations were assured. Adjustments were required to compensate for individual variations. This requirement was especially true for the blood-pressure measuring system. The clinical blood-pressure mean

*Table 18–VI.—Detailed Preflight Heart-Rate and Respiration-Rate Data*

[Flight simulation numbers 1 and 3, launch simulation, launch countdown (canceled), and launch countdown were performed on the launch pad]

| Date | Procedure | Duration of observation, hr : min | Mean | | Heart rate | | | | Respiration rate | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Heart rate, beats/min | Respiration rate, breaths/min | Number of values | ±2 standard deviations, beats/min | Range, beats/min | | Number of values | ±2 standard deviations, breaths/min | Range, breaths/min | |
| | | | | | | | Minimum | Maximum | | | Minimum | Maximum |
| February 1959. | Lovelace Clinic exercise tolerance test. | [a] 0:14 | ---- | ---- | (b) | ------ | --- | 185 | (b) | ------ | --- | --- |
| Sept. 28, 1961, and Mar. 28, 1963. | Mercury-Atlas Centrifuge dynamic simulations. | 4:18 | 83 | (b) | 177 | 57 to 109 | 58 | 151 | (b) | ------ | --- | --- |
| Apr. 13, 1962 | Altitude-chamber spacecraft checkout. | 10:29 | 79 | 18 | 161 | 54 to 104 | 60 | 129 | 117 | 11 to 25 | 12 | 28 |
| July 23, 1962 | Altitude-chamber spacecraft checkout. | 7:33 | 64 | 19 | 111 | 49 to 79 | 46 | 92 | 111 | 14 to 24 | 13 | 26 |
| Jan. 5, 1963 | Altitude-chamber spacecraft checkout. | 6:17 | 74 | 17 | 20, 000 | 56 to 92 | 56 | 102 | 123 | 10 to 24 | 10 | 26 |
| Mar. 23, 1963 | Hangar flight simulation | 2:00 | 64 | 19 | 4, 254 | 51 to 77 | 55 | 106 | 44 | 8 to 30 | 13 | 41 |
| Apr. 23, 1963 | Flight simulation No. 1 | 3:40 | 71 | 19 | 75 | 56 to 86 | 51 | 92 | 75 | 14 to 24 | 13 | 28 |
| May 7, 1963 | Mission simulation (procedures trainer). | 5:22 | 71 | (b) | 103 | 50 to 92 | 50 | 102 | (b) | ------ | --- | --- |
| May 8, 1963 | Launch simulation | 4:48 | 72 | 20 | 17, 232 | 54 to 90 | 52 | 107 | 94 | 13 to 27 | 11 | 28 |
| May 10, 1963 | Flight simulation No. 3 | 3:30 | 62 | 19 | 67 | 39 to 85 | 48 | 96 | 67 | 13 to 25 | 10 | 26 |
| May 14, 1963 | Launch countdown (canceled). | 5:41 | 71 | 20 | 19, 666 | 53 to 89 | 47 | 132 | 96 | 14 to 26 | 14 | 30 |
| May 15, 1963 | Launch countdown | 2:31 | 73 | 16 | 9, 010 | 48 to 98 | 51 | 104 | 50 | 10 to 22 | 10 | 24 |

[a] Duration determined by the maximum heart rate.

[b] Not recorded.

*Table 18–VII.—Summary of Heart-Rate and Respiration-Rate Data*

Preflight

| Date | Procedure | Duration of observation, hr:min | Overall mean | | Range of mean rates | | Range of ±2 standard deviations | |
|---|---|---|---|---|---|---|---|---|
| | | | Heart rate, beats/min | Respiration rate, breaths/min | Heart rate, beats/min | Respiration rate, breaths/min | Heart rate, beats/min | Respiration rate, breaths/min |
| September 1961 to May 15, 1963. | Centrifuge simulations and checkout procedures. | 56:23 | 72 | 19 | 62 to 83 | 16 to 20 | 39 to 104 | 8 to 30 |

Inflight

| Date | Procedure | Duration of observation, hr: min | Mean | | Heart rate | | | Respiration rate | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Heart rate, beats/min | Respiration rate, breaths/min | Number of values | ±2 standard deviations, beats/min | Range, beats/min | Number of values | ±2 standard deviations, breaths/min | Range, breaths/min |
| May 15 and May 16, 1963. | Orbital flight | 34:16 | 89 | 15 | 76,174 | 62 to 116 | 55 to 180 | 151 | 5 to 25 | 6 to 28 |

Postflight

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| May 16 and May 17, 1963. | Physical examinations. | [a] | 77 | 16 | 4 | 72 to 82 | 56 to 88 | 1 | [b] | |

[a] Not determined, not time critical.
[b] Not applicable.

*Table 18–VIII.—Detailed Preflight Blood–Pressure Data*

| Date | Procedure | Duration, hr:min | Mean blood pressure, mm Hg | Systole | | Diastole | | Mean pulse pressure, mm Hg |
|---|---|---|---|---|---|---|---|---|
| | | | | Number of values | Range, mm Hg | Number of values | Range, mm Hg | |
| **Preflight, clinical** | | | | | | | | |
| February 1959 | Lovelace Clinic exercise tolerance test | 00:14 | [a] 174/86 | | | | | |
| March 1959 | Aeronautical Systems Division dynamic tests: | | | | | | | |
| | Cold pressor | [b] | 105/74 | 13 | 100 to 112 | 13 | 70 to 82 | 31 |
| | Tilt | [b] | 109/75 | 30 | 92 to 138 | 30 | 68 to 88 | 34 |
| | Treadmill | [b] | 134/87 | 18 | 110 to 156 | 18 | 80 to 100 | 47 |
| September 1959 | Lackland USAF Hospital physical examination. | [b] | 113/70 | 4 | 110 to 116 | 4 | 68 to 72 | 42 |
| April 1962 | Physical examinations | [b] | 100/80 | 5 | 88 to 108 | 5 | 72 to 88 | 20 |
| July 1962 | Special BPMS test | [b] | 116/78 | 58 | 102 to 124 | 58 | 64 to 84 | 39 |
| July 23, 1962 | Physical examinations | [b] | 103/79 | 16 | 98 to 106 | 16 | 73 to 82 | 25 |
| March 12, 1963 | Physical examinations | [b] | 108/72 | 4 | 98 to 118 | 4 | 68 to 78 | 37 |
| Apr. 23, 1963 to May 15, 1963 | Physical examinations during final preflight checkout period. | [b] | 115/78 | 8 | 105 to 120 | 8 | 72 to 82 | 37 |
| **Preflight, blood pressure measuring system** | | | | | | | | |
| Sept. 12, 1961 | Mercury-Atlas centrifuge dynamic simulation. | 2:23 | 114/85 | 12 | 103 to 144 | 12 | 66 to 98 | 29 |
| Apr. 13, 1962 | Altitude-chamber spacecraft checkout | 10:29 | 134/91 | 10 | 128 to 148 | 10 | 70 to 124 | 43 |
| July 10 and July 23, 1962 | BPMS calibration | 3:00 | 110/79 | 73 | 96 to 128 | 69 | 63 to 88 | 31 |
| July 23, 1962 | Altitude-chamber spacecraft checkout | 7:33 | 94/71 | 8 | 79 to 111 | 8 | 61 to 79 | 23 |
| Jan. 3, 1963 | BPMS calibration | 1:00 | 108/80 | 14 | 99 to 116 | 14 | 73 to 87 | 28 |
| Jan. 5, 1963 | Altitude-chamber spacecraft checkout | 6:17 | 112/83 | 12 | 99 to 122 | 12 | 77 to 89 | 29 |
| Mar. 22 and Mar. 23, 1963 | Hangar flight simulation | 2:05 | 94/71 | 5 | 89 to 107 | 5 | 65 to 81 | 23 |
| Apr. 23, 1963 | Flight simulation No. 1 | 3:40 | 114/91 | 6 | 104 to 123 | 6 | 81 to 99 | 23 |
| May 8, 1963 | Launch simulation | 4:48 | 106/82 | 12 | 101 to 123 | 12 | 71 to 91 | 24 |
| May 10, 1963 | Flight simulation No. 3 | 3:30 | 110/90 | 2 | 107 to 112 | 2 | 89 to 91 | 20 |
| May 14, 1963 | Launch countdown (canceled) | 5:41 | 120/82 | 8 | 117 to 127 | 8 | 77 to 89 | 38 |
| May 15, 1963 | Launch countdown | 2:31 | 110/82 | 4 | 107 to 119 | 4 | 73 to 89 | 28 |

[a] Value at test endpoint, other values not available.
[b] Not determined, not time critical.

*Table 18–IX.—Summary of Blood Pressure Data*

| Date | Procedure | Duration, hr:min | Mean blood pressure, mm Hg | Systole | | | Diastole | | | Mean pulse pressure, mm Hg |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Number of values | ±2 standard deviation, mm Hg | Range, mm Hg | Number of values | ±2 standard deviation, mm Hg | Range, mm Hg | |
| Preflight, clinical | | | | | | | | | | |
| February 1959 to May 15, 1963 | Crew selection examination, special tests and preflight examinations. | [a] | 113/79 | 95 | 99 to 127 | 88 to 124 | 95 | 69 to 89 | 64 to 88 | 34 |
| Preflight, blood pressure measuring system | | | | | | | | | | |
| September 1961 to May 15, 1963 | Centrifuge simulations and preflight test procedures. | 56:09 | 112/79 | 160 | 86 to 138 | 79 to 148 | 160 | 58 to 90 | 61 to 124 | 33 |
| Inflight, blood pressure measuring system | | | | | | | | | | |
| May 15 and May 16, 1963 | Orbital flight | 34:16 | 119/81 | 12 | [b] | 109 to 131 | 12 | [b] | 73 to 89 | 38 |
| Postflight, clinical | | | | | | | | | | |
| May 16 and May 17, 1963 | Postflight physical examinations. | [a] | 91/66 | 16 | 75 to 107 | 86 to 100 | 16 | 55 to 77 | 52 to 82 | 25 |

[a] Not determined, not time critical.
[b] Not applicable.

values, shown in table 18–IX, are of particular interest and indicate that the correlation between these readings and those taken with the BPMS is valid. The stability of these calibrations was rechecked on several occasions before flight. All systems operated properly during the final preflight-preparation period.

The preflight biosensor data are presented in tables 18–VI to 18–IX. The analysis methods used were both manual and automatic.

All respiration minute rates were obtained by manual reduction; 30-second counts made from the continuous direct-recorded analog signal, with sampling intervals either every 3 or every 4 minutes. Heart rates from many of the records were determined in the same manner. Those sets can be readily identified by the relatively low number of values used. The automatic analysis utilizes a general-purpose computer to determine the intervals between all the R waves of the ECG complex in the record, and the reported values were computed from these determinations. The automatically reduced rates are readily identified by the large number of values. The validity of both of these methods has been substantiated by repeated cross-correlation of results during the two years of development of the analysis program. Although the data analysis format was arbitrarily selected, the results are fully reproducible and appear to be adequate for the present medical requirements. All blood-pressure measurements on record were incorporated in the tables.

A highly significant aspect of the preflight data is the rather wide range of values recorded, particularly heart rates, which have modified the understanding of expected or so called "normal" responses. This wide variation is a common phenomenon among healthy individuals in dynamic situations, and clearly indicates the need for the use of extreme caution in attributing changes observed in flight to weightlessness or other factors peculiar to the flight environment.

The ECG from the preflight observation period was scanned repeatedly by numerous observers. The collective opinions were that marked normal sinus arrhythmia was present with frequent occurrences of a wandering cardiac pacemaker. At times, sinus node suppression was sufficient to allow activation by the atrio-ventricular (A–V) node with escape and fusion beats. This occurrence was identified by both biphasic and negative P waves of decreased amplitude, and on occasion by changes in the ventricular complexes. Numerous such beats were noted during the countdown of the postponed launch, and one brief episode of nodal rhythm occurred during this period. This finding was considered acceptable as a normal variant in this pilot only by virtue of the extensive preflight monitoring which had shown nodal rhythm to be an incidental occurrence. These data are illustrated in figure 18–3. There was sinus bradycardia, which, at times, was followed by a sinus-generated beat and, at other times, was followed by an A–V nodal-generated escape beat. Other infrequent rhythm alterations were premature atrial and ventricular beats. The preflight data were collected in order to establish the baseline physiological responses of the MA–9 astronaut specifically using the flight biomedical instrumentation.

## FLIGHT OBSERVATIONS

Inflight biomedical monitoring spanned a time interval of 34 hours, 16 minutes, and 43 seconds on this flight. Continuous onboard recording included the first 1 hour and 35 minutes and the last 10 hours and 45 minutes of flight time until bioplug disconnect. Flight data were programed to be intermittently recorded for 1 minute of every 10 minutes between 1 hour and 39 minutes elapsed time and 23 hours and 32 minutes elapsed time. Recording of physiological data through the mid-portion of the flight was erratic and did not follow original plans because of a malfunction of the tape-recorder programer which occurred at approximately 12:00:00 ground elapsed time (g.e.t.) and continued throughout the flight. However, sufficient data points were obtained for confident extrapolation of trends of physiologic values during this portion of the flight by the astronaut's voice contacts with the ground, his use of the vox-record actuation of the tape recorder, or his turning the tape recorder temporarily to continuous to document certain inflight experiments. Data during the final portion of the flight, from 24:00:00 g.e.t. until landing, were obtained because the failed programer was over-

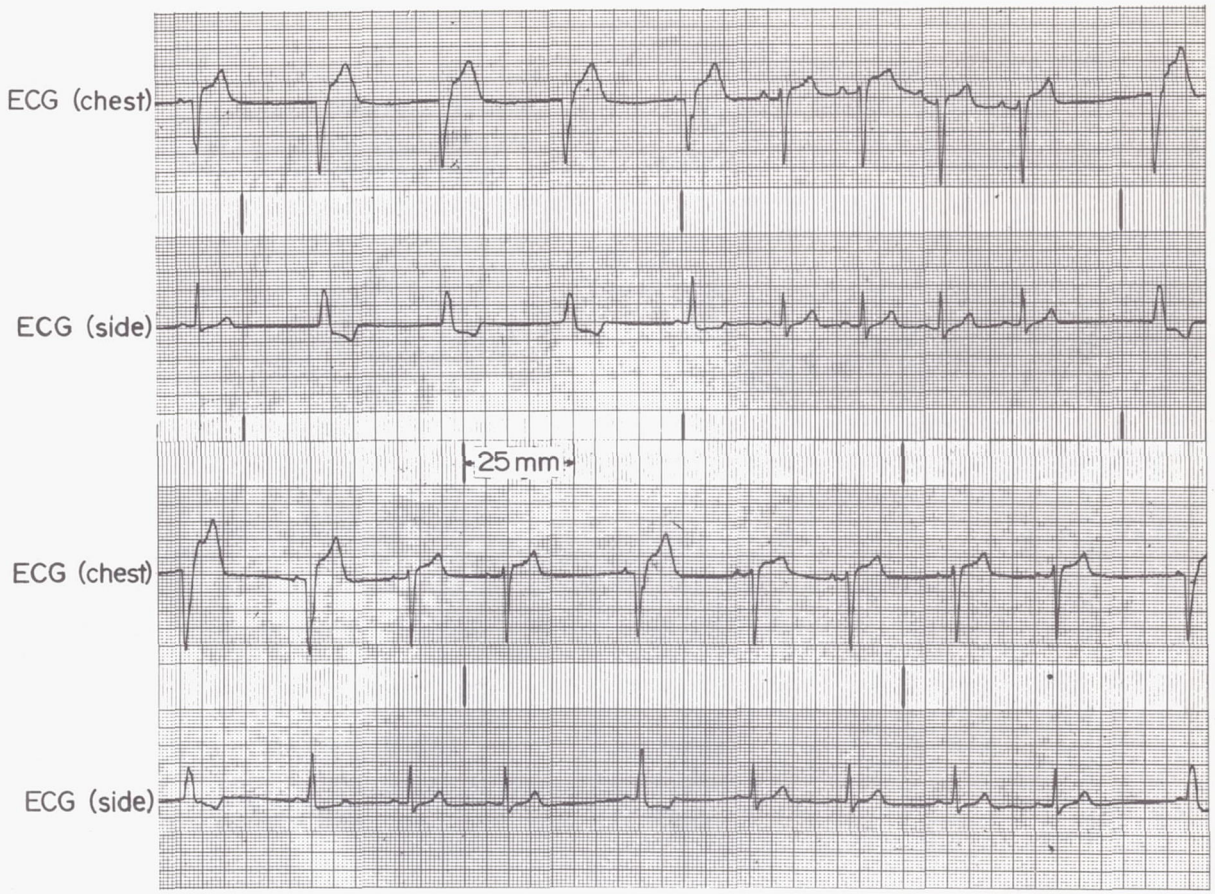



FIGURE 18–3.—MA–9. May 14, 1963, 07:42:00 e.s.t. Sample record illustrating nodal beats occurring during canceled launch countdown. Recorder speed 25 mm/sec.

ridden by the astronaut's selection of continuous recorder operation. During the period when the astronaut was resting quietly or was asleep, essentially no medical data were obtained on the onboard recorder; consequently mean heart-rate values for the entire duration of the flight are probably biased on the high side of a true mean. Data from the onboard recorder have been supplemented by data obtained during network station passes throughout the mission, and an exceptionally valuable short period of recording was obtained onboard the carrier during egress of the astronaut. The inflight responses are summarized in tables 18–VII and 18–IX. Heart-rate response, including mean rates, was obtained through a computer reduction of the inflight data from the onboard tape recorder.

Respiration rates were obtained by the manual reduction of 30-second periods every 3 minutes during the period of continous recording and from 30-second averages taken at all other short intervals when data were available from the onboard tape recorder. Blood pressures were obtained according to the flight plan with only very minor variations. These values were with few exceptions not recorded on the onboard recorder since the astronaut was generally quiet while sending the blood pressure, and therefore the tape recorder was not operating. However, the values were received at ground stations in every instance and read in real time by medical monitors. The readings were subsequently verified by postflight analysis of the tracking-site data. Body temperature was sampled intermittently during the flight with an oral thermistor, which the pilot placed under his tongue on four of the five planned occasions. One additional oral temperature was requested and obtained during the flight. Body temperatures obtained in flight and listed in table 18–X were all within an acceptable range.

*Table 18–X.—Oral Temperatures Obtained in Flight*

| Ground elapsed time, hr : min : sec | Oral temperature, °F |
|---|---|
| 1:10:00 | 98. 5 |
| 6:00:00 | 100. 0 |
| 10:25:00 | 100. 0 |
| 12:25:00 | 99. 0 |
| 23:50:00 | 98. 0 |

The overall mean heart rate recorded during the period when the inflight recorder was operative was 89 beats per minute, and the overall respiratory rate recorded from available data was 19 breaths per minute. The significant events of powered flight showed corresponding increases in heart rate and respiratory rate, as has been the case in all manned Mercury flights. The pilot's heart rate at booster-engine cut-off (BECO) was 147 beats per minute; at launch-escape-rocket ignition, 154 beats per minute; and at sustainer-engine cut-off (SECO), 144 beats per minute. Within 2 minutes after SECO, the heart rate subsided to about 110 beats per minute and then gradually declined over the next 13 minutes to rates of 80 to 100 beats per minute for the remainder of the first orbital pass. Respiratory rate was 28 breaths per minute at BECO, between 25 and 30 breaths per minute through SECO, and then declined to rates of 18 to 20 breaths per minute within the first 15 minutes of weightless flight.

Heart rate remained stable around 80 beats per minute throughout the first 8 hours in space except during periods when the astronaut announced on the tape that he was undergoing some specific exertion such as emptying the condensate tank or removing equipment from the equipment kit. During these intervals, rates would increase to values from 100 beats per minute to as high as 130 beats per minute for very short times.

At 8:25:00 g.e.t., the pilot specifically mentioned struggling with his writing desk. At this time, his heart rate rose to 96 beats per minute and then promptly settled back to its resting rate of about 80. The longer period of observation and the opportunity which this flight afforded to correlate pilot activities with heart and respiratory rates permit a tentative appraisal of the effect on these rates of exertion under equally cramped circumstances at 1g. There does not appear to be a significant difference in terms of heart-rate and respiratory-rate response in the two situations. This impression was further borne out in the two planned exercise periods in which there was similarity between the response to exercise in orbital flight and the response to exercise in preflight practice sessions, as shown in table 18–XI.

When the flashing light was deployed at about 3:26:00 g.e.t. his heart rate rose to a sharp peak of 134 beats per minute and then promptly declined to 95 beats per minute while the pilot was maneuvering the spacecraft in an attempt to sight the flashing light.

The respiratory rate sensor malfunctioned during the flight. The failure was subsequently traced to a separation of the lead wire from the electrode, which was attached to the left lower chest. The first sign of respiration-sensor failure ocurred at 7:08:00 g.e.t.; and throughout the remainder of the flight, the respiratory-rate recording was intermittent. Sometimes, the trace appeared to be a faithful replica of the pilot's breathing, but at other times it was entirely unreliable or without apparent relationship to respiration. The respiratory rates during the last portion of the flight are tentative rates based on the appearance of the pneumograph waveform during periods when evidence available indicated it was following changes in thoracic volume. Typical signals of properly operating biosensors are illustrated in figure 18–4.

During the sleeping period, heart rates recorded on passes over tracking stations were generally as low as 50 and averaged between 55 and 60 beats per minute. However, when the pilot awoke and announced anything which was recorded on the onboard recorder, his heart rate immediately rose to about 80 which is the same value as during his working period earlier in the flight. After about 23:32:00 g.e.t. and for the remainder of the normal orbital flight, the astronaut's mean heart rate rose to a value of about 100 beats per minute. His first indication of a spacecraft system malfunction occurred at about 23:59:00 g.e.t. when he noticed that the 0.05g relay light had come on. Heart rate at this time rose sharply to 148 beats per minute and then rapidly declined to the low of

*Table 18–XI.—Summary of Calibrated Work*

| Prework | | | | | Work | | Postwork | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Heart rate, beats/min | | Blood pressure, mm Hg | | | Heart rate, beats/min | | Heart rate, beats/min | | Blood pressure, mm Hg | | |
| Mean | Range | Mean | Range | | Mean | Range | Mean | Range | Mean | Range | |
| | | | Systolic | Diastolic | | | | | | Systolic | Diastolic |
| Preflight, 5 calibrated work periods | | | | | | | | | | | |
| 74 | 60 to 100 | 104/81 | 89 to 113 | 77 to 85 | 115 | 91 to 160 | 85 | 61 to 120 | 111/79 | 89 to 137 | 71 to 89 |
| Flight, 2 calibrated work periods | | | | | | | | | | | |
| 89 | 80 to 105 | 117/77 | 117 | 77 | 131 | 120 to 145 | 106 | 124/95 | 90 to 130 | 119 to 129 | 89 |

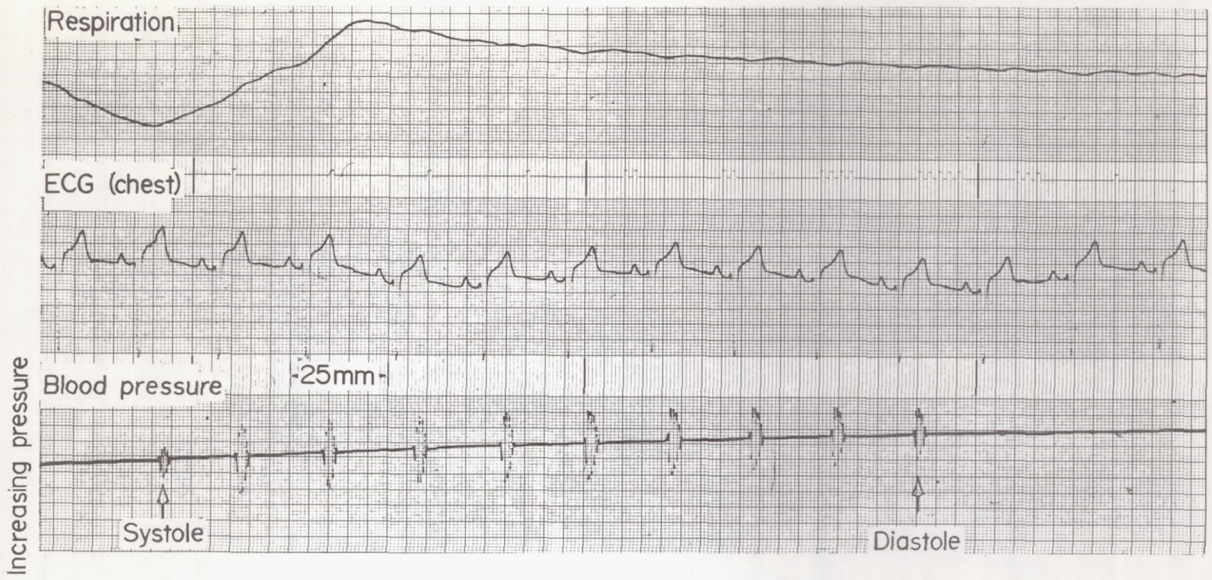



FIGURE 18–4.—MA–9. 12:29:52. Sample of typical biosensor data received at a range station. Blood pressure 117/3 mm Hg. (Recorder speed 25 mm/sec.)

60 beats per minute and stabilized at a rate of around 100 beats per minute. After a preliminary analysis of the nature of the malfunction indicated by this 0.05g light, the pilot's heart rate varied, with a peak of 142 beats per minute while he was engaged in checking his ASCS system at approximately 30:08:00 g.e.t. Again, the heart rate declined rapidly to its resting level of approximately 100 beats per minute.

At about 32:41:00 g.e.t., the pilot was advised to take 5 mg of dextro amphetamine orally which he did very shortly after receiving the advice. His heart rate rose gradually beginning at 33 hours elapsed time, with rather marked swings in rate between levels as high as 140 beats per minute and lows of about 80 beats per minute throughout the remainder of the flight. A significant change in heart rate occurred at retrofire when the heart rate rose to 166 beats per minute for no longer than 20 seconds.

The heart rate during reentry varied between 120 and 140 beats per minute until drogue parachute deployment when it spiked to 184 beats per minute. It then gradually declined to 164 beats per minute when bioplug disconnect was accomplished subsequent to main parachute deployment.

The changes in heart rate throughout this flight seem to fall readily into two categories. Moderate increases in rate with gradual return to the normal resting rate were seen in response to physical exertion. The peak heart rate noted during the flight generally corresponded to levels which have been seen following an equivalent amount of exertion under 1g. A sharper rise of heart rate to high levels in excess of 140 beats per minute was seen as a response when the astronaut was evidently emotionally alerted to a highly significant change in his environmental situation.

The ECG intervals were well within normal physiologic limits during the major portion of this flight. The A–V nodal beats noted during the prelaunch period were rarely seen during the 34½ hours of flight monitoring. A careful review of all flight records revealed that data from both leads of ECG showed periodic changes in the character of the P wave and the P–R interval, which are consistent with a wandering pacemaker. There were frequent prolonged sinus pauses during the flight which generally are associated with deep inspiration by the pilot, and in the great majority of instances a sinus beat, rather than a ventricular escape, followed the pause. One period in which this rule did not hold was during the sleeping time as the astronaut was passing over the Rose Knot Victor tracking ship. At 17:10:00 and 18:45:00 g.e.t., the medical monitor reported a nodal rhythm which was verified during the postflight examination of the records. Figure

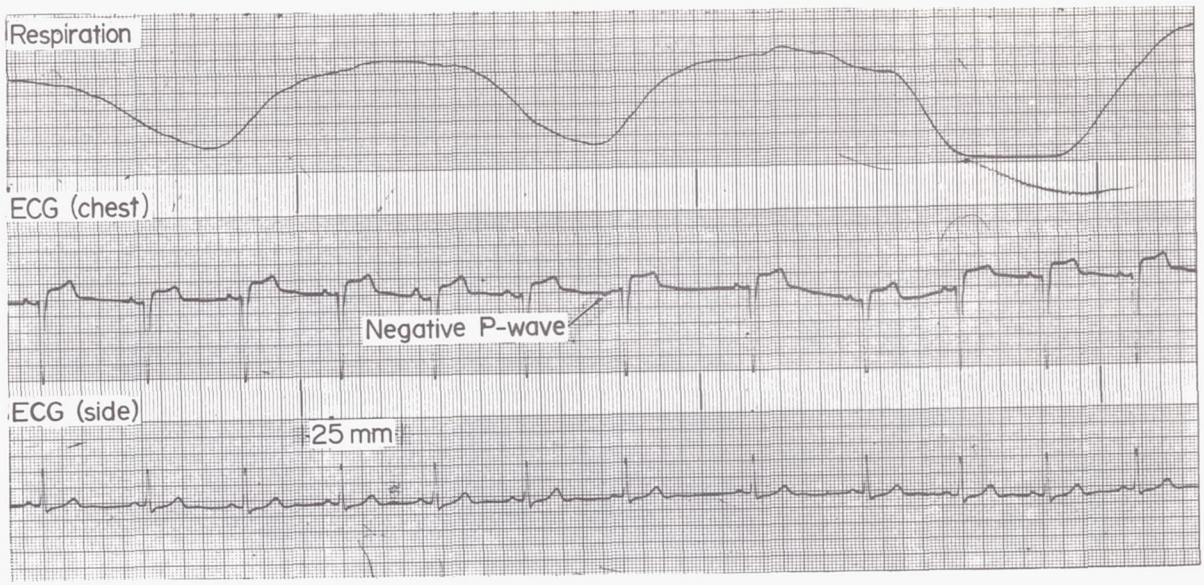



FIGURE 18–5.—MA–19. 16:11:30. Sample of biosensor record at a range station illustrating one of the frequent occurrences of sinus arrhythmia with wandering of the cardiac pacemaker. In this sample, the negative P wave suggests inverse depolarization from the atrioventricular node. Similar changes were observed before flight. (Recorder speed 25 mm/sec.)

18–5 illustrates this variation. Late in the flight, the sternal ECG lead became rather noisy with a marked fluctuation of the baseline. This fluctuation appeared at times to be synchronous with respiration and at other times to bear little or no relationship to respiratory movements. At this period in the flight, sinus arrhythmia was somewhat more pronounced that it had been early in the flight. A recurrent finding on the record consisted of a simultaneous disruption of the sternal ECG recording with a sharp negative impulse on the relatively insensitive respiratory channel and a sinus pause showing on the side-to-side ECG lead. It is believed that this characteristic pattern resulted from either a habitual deep sighing breath taken by the pilot or perhaps a repeated stretching motion made in an attempt to relieve his cramped position.

Blood pressures did not vary remarkably during the flight from preflight values, as shown in table 18–IX.

Postflight analysis of the film badges worn by the astronaut revealed a total radiation dose well below a level of medical concern. (See paper 12 for a report on the radiation measurement.)

With regard to symptoms related to the flight experience, the pilot repeated the observations of each of his predecessors that the g-forces are readily tolerated and that the sensation of weightlessness is an entirely pleasant experience to which he adapted readily. Astronaut Cooper noticed that his perspective within the spacecraft cabin was altered during the first few minutes of weightless flight. Specifically, he observed that after SECO and during the first 20 minutes or so of weightlessness he felt that the equipment kit located near his right arm was rotated 90°. A similar phenomenon of orientation was reported by the MA–7 pilot. See reference 2. This was not a troublesome illusion to the pilot and gradually vanished as he became accustomed to the altered sensory cues of orbital flight.

The astronaut stated that he did not feel particularly hungry during most of the flight and ate primarily because it had been scheduled. However, later in the flight he did feel hungry on one occasion and after eating felt better. Because of problems with the food containers and water nozzle during flight, he was unable to reconstitute properly the freeze-dehydrated food and could only eat one-third of a package of beef pot roast. Therefore, he subsisted on bite-sized cubed food and bite-sized peanut butter "sandwiches." He avoided the bite-sized beef sandwiches, since they had crumbled in

their package. His caloric intake during the flight was only 696 calories of the 2,369 calories available to him at launch. He rapidly tired of the cubed "snack-type" foods and this contributed to his low caloric intake. Typical samples of the food types carried aboard from the MA–9 flight are shown in figure 18–6.

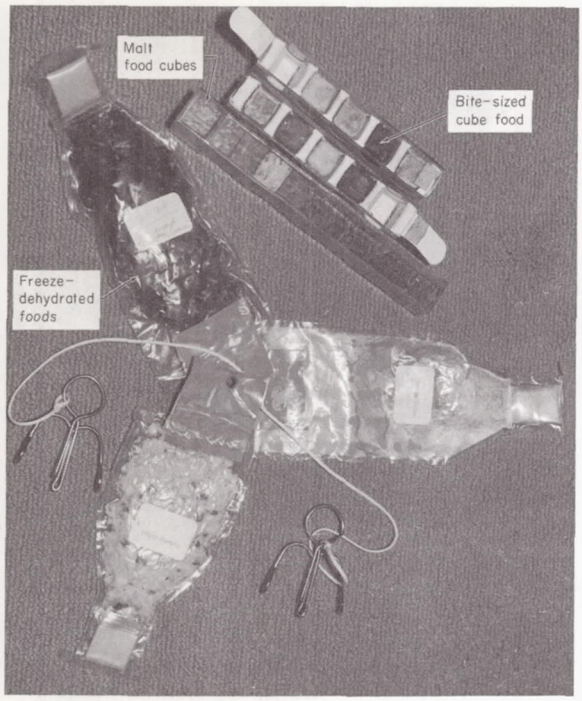



FIGURE 18–6.—Types of food used during MA–9 flight.

The astronaut's water intake was also limited. When the condensate transfer system would no longer permit fluid storage in the 3.86–pound–capacity main condensate bag during the flight he was forced to put condensate water into one of the drinking-water tanks before he had consumed all of its contents. Normal operational procedures required the exclusion of condensate water as a drinking-water source. He began drinking small amounts from his survival-kit water supply, as planned, but he wished to conserve this supply as much as possible. He was not really thirsty until during the last orbital pass, but he was so busy at that point that he did not take time to drink. Because condensate water was placed into the drinking-water tank in which an unknown amount of drinking water remained, it is impossible to make a precise statement as to his water intake during flight, but he did consume more than 1,500 cc.

He urinated without difficulty several times during flight and stated that bladder sensations were normal. The urine collection and transfer system worked well, and separate urine samples were obtained at four different times during the flight. It required, however, a considerable amount of time and effort to transfer the urine to the storage bags manually.

The astronaut had a very good sleep the night prior to launch and was as rested as possible. He found, even early in the flight, that when he had no tasks to perform and the spacecraft was oriented such that the earth was not in view from the window, he easily dozed off for brief naps. This dozing did not occur during times when there were tasks to perform or items to see through the window. During the period designated for sleep, he slept only in a series of naps lasting no more than 1 hour each. His total sleep time was about 4½ hours. He awoke from these 30– to 60–minute naps feeling alert and rested, but 30 to 45 minutes later he would again doze off. He stated that if there had been another person along to monitor the systems, particularly the environmental control system, he could have slept for much longer periods, but still "no more than 4 to 6 hours in a day." Table 18–XII lists estimated inflight sleep periods.

He had a brief period of confusion the first time or two that he awoke in that he did not realize exactly where he was. However, it took him only a very few seconds to become completely awake and oriented. He reported that this brief period of confusion did not occur later in the flight. The pilot stated that he slept "perhaps a little more soundly" than on earth. He did dream, but he did not remember the contents of the dreams. This is consistent with his past experience.

He felt that being strapped into the seat made little difference in his sleep, but he definitely had the feeling he was sleeping sitting up. He noted when he awoke that his arms were floating out in front of him, and because of his concern that he might inadvertently trip a critical switch during sleep, he folded his hands and hooked his thumbs under the helmet restraint cables. He was never startled or alarmed to awaken and see his hands floating in front of his faceplate.

*Table 18–XII.—Inflight Sleep Periods*

[Other unrecorded naps occurred]

| Time, g.e.t. | Estimated duration, min | Source |
|---|---|---|
| 02:10:15 to 02:14:00 | 4 | Onboard tape. |
| 05:40:00 to 05:45:00 | 5 | Astronaut record. |
| 13:50:00 to 14:46:00 | 56 | Onboard tape. |
| 14:20:00 to 14:47:00 | 27 | Astronaut record. |
| 15:11:00 | (a) | Onboard tape. |
| 15:20:00 to 16:05:00 | 45 | Astronaut record. |
| 16:28:11 | (a) | Onboard tape. |
| 16:50:00 to 17:50:00 | 60 | Astronaut record. |
| 08:20:00 to 18:25:00 | 5 | Astronaut record. |
| 18:40:00 to 19:27:00 | 47 | Astronaut record. |
| 19:38:39 | (a) | Onboard tape. |
| 21:22:44 | (a) | Onboard tape. |
| 27:26:08 | (a) | Onboard tape. |
| Total sleep recorded: 4 hours and 9 minutes. | | |

[a] Short naps, duration not determined.

The oral temperature probe was easily handled by the pilot. It was necessary to use a small hand mirror to check its position on the right ear muff to be sure it was not extending beyond the helmet, but at no time did it interfere with closing the faceplate.

The only real discomfort experienced during the flight was associated with the pressure suit being pulled tightly across the pilot's knees. By the sixth or seventh orbital pass, his knees were becoming quite uncomfortable. He alleviated this discomfort somewhat by periodically sliding his feet up past the normal foot position into the tower area of the spacecraft. This action permitted the straightening of his legs to relieve most of the pressure and also allowed him to pull on the legs of the suit to gain a little slack around his knees.

The astronaut took 5 mg of dextro-amphetamine sulfate approximately 1 hour 20 minutes prior to retrofire on advice of the MCC surgeon. He stated that within 20 minutes he felt much more alert and confident and seemed to be "more on top of things." He had less tendency to drop off to sleep for the remainder of the flight. There was no apparent degradation in the pilot's performance following this medication. The pilot stated that the drug, as far as he could tell, had the same effects as test doses taken prior to flight.

During the last two orbital passes, the carbon-dioxide partial-pressure ($PCO_2$) gage was noted to indicate a rise in the amount of carbon dioxide in the suit. The astronaut actuated the emergency oxygen flow rate for 30 seconds. It did not seem to change the pilot's onboard reading noticeably, although telemetry signals indicated a slight drop. At this time the pilot closed his faceplate and felt that his respirations were deeper and more rapid. This change in respiration could not be confirmed by postflight examination of respiration and heart rate recordings. Although he felt more comfortable with the faceplate open, he kept it closed during the final orbital pass and the reentry as planned. The $PCO_2$ gage indicated about 5 mm Hg at reentry. This concentration is not enough to cause symptoms of hypercapnia on the ground, and there was no apparent interference with the pilot's normal responses.

### Postflight Observations

The spacecraft landed in the water about 4.5 miles from the recovery ship, the *USS Kearsarge*, and was placed on deck approximately 40 minutes later. In order to gain medical data as early as possible, the NASA flight surgeon

aboard the recovery ship was equipped with an 8-foot extension cord for the biomedical cable. Immediately after the hatch was opened, this cord was attached to the astronaut's biosensor plug and blood pressure fitting and connected to the spacecraft onboard recorder to record blood pressures and ECG before, during, and after egress. This system was extremely effective in deriving egress data.

The astronaut was then taken to the ship's sick bay where a comprehensive medical examination and preliminary debriefing were performed. The remainder of the debriefing was conducted by the NASA flight surgeon in the admiral's inport cabin. The astronaut spent 48 hours on board the ship. Details of his activities during this 48-hour period are shown in table 18–XIII.

*Table 18–XIII.—Pilot Postflight Activities*

| Date, 1963 | Time, local Midway [a] | Activity |
|---|---|---|
| May 16 | 12:25 p.m | Landing. |
| | 12:55 p.m | Spacecraft on deck. |
| | 1:09 p.m | Blood pressure, recumbent in spacecraft. |
| | 1:12 p.m | Egress and blood pressure standing. |
| | 1:15 p.m | Physical examination begun in recovery ship sick bay. |
| | 1:45 p.m | First tilt table procedure. |
| | 3:00 p.m | Examination completed. |
| | 3:30 p.m | First postflight urination. |
| | 3:42 p.m | Second tilt table procedure. |
| | 4:10 p.m | First postflight meal. |
| | 5:45 p.m | First postflight bowel movement. |
| | 7:11 p.m | Third tilt table procedure. |
| | 9:30 p.m | To bed. |
| May 17 | 7:00 a.m | Awakened. |
| | 7:40 a.m | Fourth tilt table procedure and brief medical examination. |
| | 8:00 a.m | Breakfast. |
| | 9:00 to 11:00 a.m | Self-debriefing. |
| | 2:00 to 5:00 p.m | Technical debriefing. |
| | 7:00 to 9:00 p.m | Medical debriefing. |
| May 18 | 1:00 p.m | Left recovery ship. |
| May 20 | 9:00 a.m. e.s.t | Comprehensive postflight medical examination at Patrick Air Force Base, Fla. |

[a] To convert times to e.s.t., add 6 hours.

The postflight examination began prior to egress from the spacecraft. Approximately 40 minutes after landing, two measurements of the astronaut's blood pressure were recorded while he was still lying in the spacecraft on the deck of the recovery ship. He was then able to egress from the spacecraft without assistance and stand erect on the deck while his blood pressure was again recorded on the onboard tape. Later examination of this 3½ minute record shows that, while he was still in the spacecraft, his blood pressures were 101/65 and 105/87, with a corresponding heart rate of 132 beats per minute. During egress and immediately thereafter while standing upright on the deck, his heart rate rose to 188 beats per minute with atrioventricular dissociation. At that point, another blood pressure recording was attempted and, although the apparatus appeared to cycle normally, no pressure pulses were seen on the recording. His heart then returned to a normal sinus rhythm with a rate of 92 beats per minute at sensor disconnect.

After standing on the deck for approximately a minute, the pilot began to look pale and, although his face was already wet, new beads of perspiration appeared on his forehead.

He swayed slightly and reported symptoms of impending loss of consciousness including lightheadedness, dimming of vision, and tingling of his feet and legs.

The cable was immediately disconnected and, with support at each arm, he began to walk away from the spacecraft. After a few steps, 5 to 10 seconds later, he was able to walk without assistance and to salute the ship's commanding officer. There were no other objective changes of this kind throughout the postflight examination and debriefing period.

The remainder of the physical examination was conducted in the ship's sick bay and was completed within 2 hours after landing. During desuiting it was noted that the astronaut was soaking wet, presumably with perspiration. His hands had the white, wrinkled appearance characteristic of prolonged submersion in water. His feet and socks were dry. He complained of being thirsty and his voice was dry and hoarse. He participated actively in the desuiting and examination but appeared tired and less talkative than usual.

The urine collection device contained 107 cc of urine. When the soaking wet underwear was removed, the lead wire to the lower left of the pneumograph sensor on the chest was seen to be disconnected. It is not known whether it separated prior to this time, although it appears probable that it was loose and was making partial contact, held by the plastic insulation sleeve until the suit was removed. There were some evidences of pressure on the skin at all lateral sensor locations, but no signs of irritation by sensors, or paste. All sensors were securely in place and the electrode paste seemed to have maintained its normal consistency. At the sensor locations on the left lateral chest, there were narrow semicircular marks that looked like very shallow cuts with a sharp blade. These cuts may have been caused by the thin edge of the tape where the rubber sensor disc slightly overlapped it.

There were painful and slightly swollen red areas over each patella caused by the pressure suit having been pulled tightly across the anterior knee when the knee was flexed. Other reddened areas were found over each posterior inferior iliac spine and the posterior spinous process of the fifth lumbar vertebra. There was a diffuse redness over the right lateral iliac area, but none over the left.

Additional findings of note were a bilateral conjunctivitis, which probably resulted from drying of the eyes by the constant oxygen flow and a slight reddening around the left tympanic membrane. The astronaut complained that he had a little trouble clearing his left ear during descent. Both ears "crackled" for 6 to 8 hours after recovery as the oxygen in the middle ear was gradually absorbed and replaced with air. This condition is commonly seen in aviators when they have been breathing 100-percent oxygen.

Tilt table studies were performed at 1, 3, 6½, and 19 hours after landing. At no time did the astronaut have any subjective complaints, nor were objective changes noted except in heart rate and blood pressure. Specifically, there were no unusual color changes in the feet, as had been noted following the MA–8 flight. The results of the tilt table studies are tabulated and discussed under Special Studies.

The medical findings during the initial examination after desuiting are shown in table 18–II and included a blood pressure of 90/80 mm Hg while supine, a heart rate of 86 beats per minute, a respiration rate of 16 breaths per minute, a body weight of 139¼ pounds, and a body temperature of 99.4° F taken orally. Three hours after landing, his urine showed a specific gravity of 1.031, and the hematocrit was 49. These findings, combined with the clinical evaluation, indicate a moderate dehydration. As has been indicated elsewhere, this dehydration resulted from a reduced intake of food and water during the flight. Detailed results of the blood and urine analyses are contained in tables 18–III to 18–V. The reversal of the ratio of lymphocytes to polymorphonuclear leukocytes during the week following the flight, without a significant change in the total count, has not been explained. This ratio has since returned to normal. A clinical electrocardiogram and a chest X-ray completed the initial postflight examination. The chest X-ray showed no changes when compared with that taken before the flight on May 12, 1963. The ECG showed a moderate rightward shift in the QRS and T axes when compared to that of May 12, 1963.

The astronaut slept very soundly for 9½ hours and awoke cheerful and eager to complete the debriefing activites.

A brief examination the following day showed that the conjunctival irritation, the hoarseness of his voice, most of the skin pressure marks,

and most of the evidence of dehydration had disappeared. The areas of pressure over the knees were still painful and somewhat more swollen than on the previous day. The sharp semicircular marks were still much in evidence and remained visible for several days.

*Table 18–XIV.—Period of Pilot's Weight Changes*

During the 3-week period prior to flight, the pilot's maximum weight was 149¼ lb and his minimum weight was 146 lb. His weight on launch morning was 147 lb and his weight on the recovery ship was 139¼ lb.]

| Date | Activity | Duration, hr | Weight loss, lb |
|---|---|---|---|
| | Preflight | | |
| Jan. 5, 1963 | Altitude-chamber spacecraft checkout procedure. | 9 | 3. 5 |
| Apr. 23, 1963 | Flight simulation | 7 | 2. 0 |
| May 8, 1963 | Launch simulation | 8½ | 3. 0 |
| May 10, 1963 | Flight simulation | 6 | 2. 0 |
| May 14, 1963 | Canceled launch | 8 | 1. 3 |
| | Flight | | |
| May 15/16, 1963 | Orbital flight | 34⅓ | 7. 75 |

Table 18–XIV shows the pilot's weight loss during several preflight activities and the in-flight experience. Intake and output records for the first 24 hours after recovery indicate a fluid intake of 3,900 cc and a urine output of 545 cc.

The pilot returned to the launch site on the fourth day following launch and was examined the following morning. The same medical specialists who examined him prior to flight found him to be in excellent health. The only changes noted were the persistent slight erythema and tenderness of both patellae resulting from the pressure areas in the suit, a continued rightward shift in the QRS and T axes of the ECG, and persistence of the previously noted alteration in blood count. The ECG shift had become less apparent, however. The laboratory studies of blood and urine are contained in tables 18–III to 18–V.

The pilot remained in good health and maintained his high morale following this examination. He participated in debriefing sessions and other postflight activities without further medical change.

## Special Studies

### Tilt Test Evaluation

The medical examination performed immediately after the MA–8 recovery suggested an alteration in the pilot's cardiovascular responses to position changes (ref. 1). In order to obtain more quantitative measurements of these responses, an operational tilt procedure was developed for shipboard use. This procedure utilized a Stokes' Litter with cross-bars added for lifting and stabilization. The modifications permitted a tilt of 70° from the horizontal in 3 to 4 seconds. The individual being tested was comfortably secured in the litter, without circulatory interference, by straps across the knees and the upper chest.

Heart-rate and blood-pressure measurements were taken at least every minute in all tests and were chosen as the primary indicators of altered functions, in conjunction with observation of visible reactions and subjective comments. Operational use called for minute heart rates calculated from 15-second counts of the right radial pulse with clinical blood pressures taken from the left arm. Greater capability in the

Space Medicine Laboratory in Hangar S permitted simultaneous determination of both clinical and BPMS blood pressures and continuous recording of respiration rate and ECG from the biosensor sytem. Minute heart rates were determined from the directly recorded biosensor data by using 12-second counts made every 30 seconds.

Minute respiration rates were determined from 30-second counts made each minute. There were no apparent differences between the clinical and biosensor values.

The procedure was carried out in the following manner. After four sets of similar control values, the individual was tilted for 5 minutes and values were sampled at least every minute. Then the subject was returned to the horizontal position for a recording of at least four more sets of similar values. Thus, the minimum time for the complete test was 13 minutes. In order to superimpose a further cardiovascular stress, a modified Flack Test was used in some of the tilts. This test utilizes a tube with a small orifice through which the individual exhales after a maximum inspiration, producing a constant pulmonary overpressure of 40 mm Hg. The Flack Test lasted 15 seconds and was conducted from 3½ to 4½ minutes after the individual was tilted to the 70° position.

Preflight results were obtained from 11 tilt tests on the flight astronaut from January 5 to May 10, 1963. Flack Tests were performed with four of the tilts. All of these tilts were performed in conjunction with a spacecraft checkout procedure which required at least 2 hours in the spacecraft couch in the semisupine position. The time between the prerun tilts and the procedure varied from 1 to 5 hours because of uncontrollable operational factors. In each case, the postrun tilts were conducted from 5 to 15 minutes after the procedure, and on Jan-

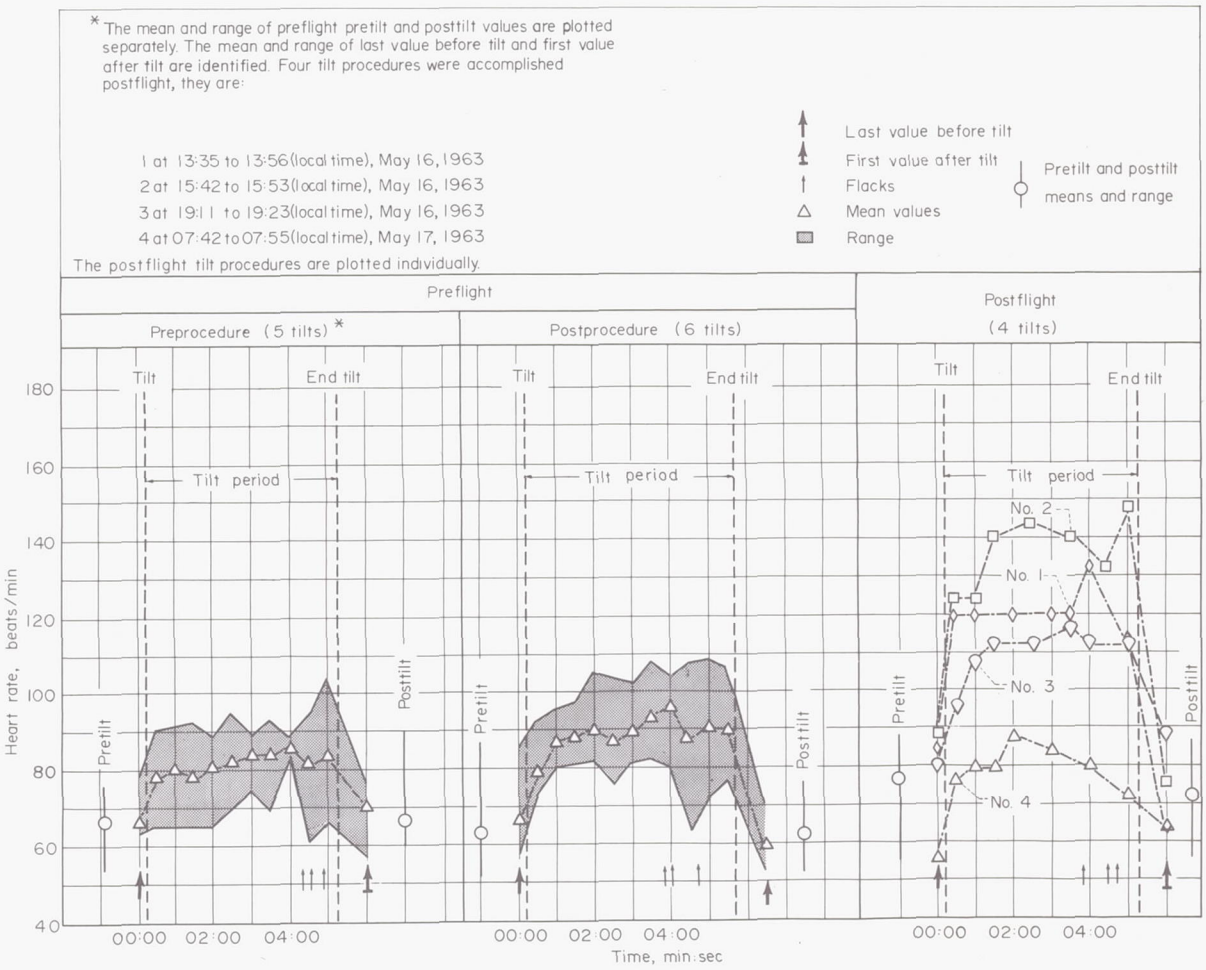



FIGURE 18-7.—Tilt studies—heart rate responses—MA-9.

uary 5, 1963, a second postrun tilt was performed 1 hour after the first.

The heart-rate and blood-pressure values are summarized in table 18–XV and illustrated in figures 18–7 and 18–8. The preflight results fall within the ranges reported in the literature. In the prerun period, most heart rates were between 55 and 80 beats per minute. The tilt produced a rise in heart rate varying from 5 to about 20 beats per minute within 30 seconds. This reading gradually increased during the first 2 minutes to rates of 80 and 90 beats per minute, at which point it stabilized. Posttilt values between 100 and 110 beats per minute occurred after a 6½ hour run, which was more than twice as long as any of the other runs.

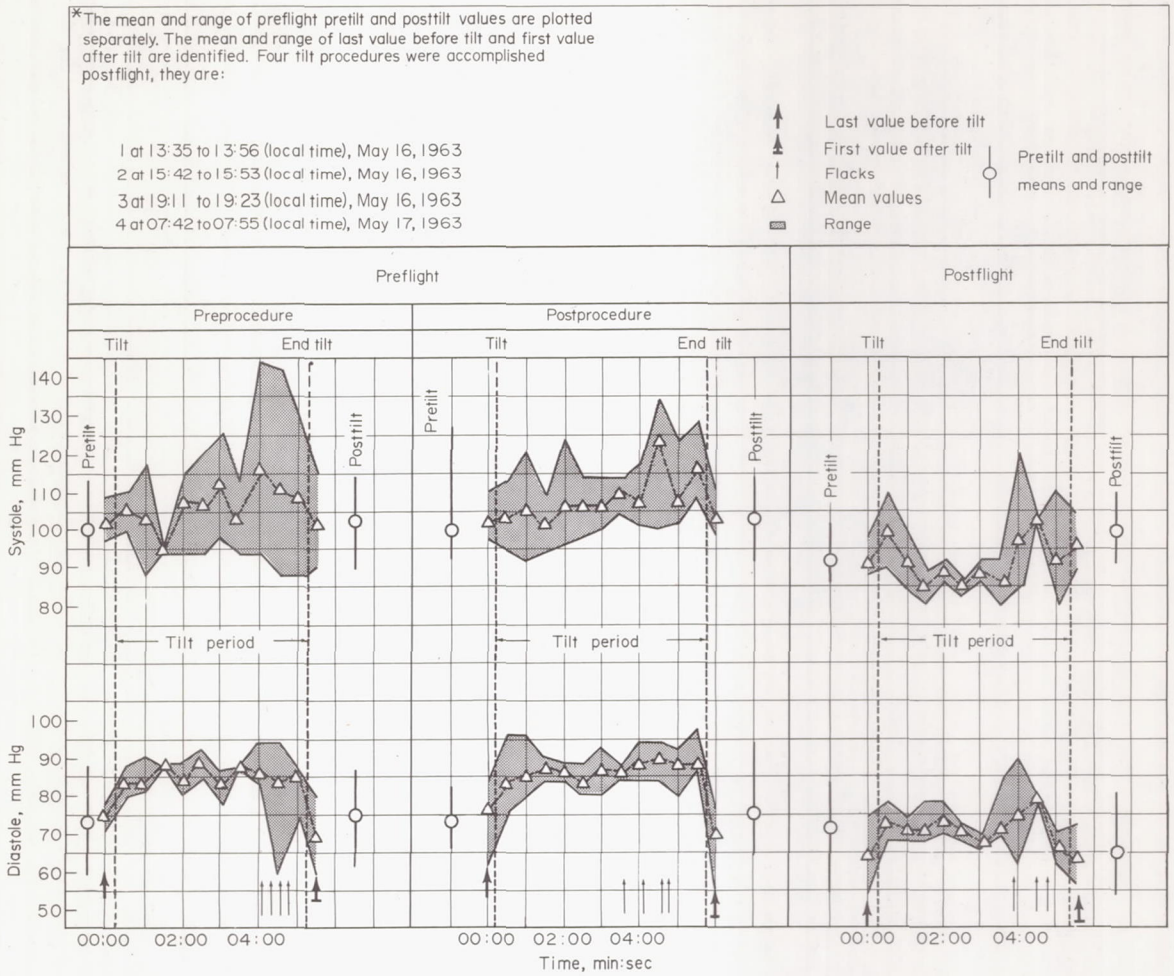



FIGURE 18–8.—Tilt studies—blood pressure responses—MA–9.

At the beginning of the Flack Test, a bradycardia for 3 or 4 beats usually occurred, followed by an increase in rate to 80 to 90 beats per minute. On several occasions, the maximum observed rates of 110 beats per minute followed a Flack Test. The sudden release of the increased intrathoracic pressure again produced a transient bradycardia followed by an "overshoot" of 10 to 15 beats per minute. Conclusion of the tilt period consistently produced an immediate drop in rate to the pretilt range. Respiration rates were without significant change and are not reported. The increases in diastolic blood pressure were the most remarkable produced by the tilt. The mean increase was 15 mm Hg, but many of the diastolic pressures rose 20 to 30 mm Hg. An initial systolic drop was followed by a compensatory rise. Postrun tilts produced somewhat more striking blood-pressure changes, with narrowing of some pulse pressures to as little at 6 mm Hg. The maximum systolic levels followed Flack Tests, without an associated diastolic change of significance.

*Table 18–XV.—Summary of Tilt Studies*

| Subject | Number of determinations | Pretilt | | | | | Tilt | | | | | Posttilt | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Heart rate, beats/min | | Blood pressure, mm Hg | | | Heart rate, beats/min | | Blood pressure, mm Hg | | | Heart rate, beats/min | | Blood pressure, mm Hg | | |
| | | Mean | Range | Mean | Range | | Mean | Range | Mean | Range | | Mean | Range | Mean | Range | |
| | | | | | Systolic | Diastolic | | | | Systolic | Diastolic | | | | Systolic | Diastolic |
| Preflight | | | | | | | | | | | | | | | | |
| Cooper preprocedure | 5 | 66 | 53 to 76 | 100/73 | 91 to 112 | 60 to 87 | 82 | 60 to 105 | 100/86 | 88 to 144 | 60 to 94 | 66 | 60 to 90 | 102/75 | 89 to 114 | 60 to 88 |
| Cooper postprocedure | 6 | 64 | 51 to 85 | 99/74 | 92 to 128 | 66 to 82 | 85 | 72 to 108 | 105/87 | 92 to 134 | 60 to 97 | 62 | 52 to 76 | 102/75 | 90 to 114 | 64 to 94 |
| Cooper and Shepard (all preflight tilts) | 15 | 67 | 55 to 85 | 100/71 | 90 to 112 | 60 to 82 | 86 | 60 to 117 | 107/86 | 88 to 145 | 64 to 98 | 64 | 52 to 80 | 103/72 | 90 to 114 | 60 to 94 |
| Postflight | | | | | | | | | | | | | | | | |
| Cooper[a] | 3 | 83 | 76 to 81 | 89/64 | 86 to 90 | 52 to 82 | 123 | 96 to 144 | 90/73 | 80 to 110 | 68 to 84 | 76 | 64 to 88 | 98/69 | 90 to 106 | 58 to 80 |
| Cooper[b] | 1 | 58 | 56 to 60 | 98/61 | 96 to 100 | 60 to 62 | 80 | 76 to 88 | 94/68 | 86 to 100 | 64 to 78 | 60 | 56 to 64 | 102/56 | 96 to 108 | 54 to 58 |

[a] Tilts between 1 and 7 hours after landing.
[b] Tilt 18 hours after landing.

The ECG demonstrated expected alteration of the QRS axis secondary to position change. Decrease in size of the QRS was especially prominent in the chest lead as a consequence of R-wave depression. There were sinus pauses with an occasional aberrant complex of ventricular origin. The usual pretilt sinus arrhythmia disappeared with the rate increases. The Flack Test produced dropped beats and occasional premature ventricular contractions during the period after sudden release.

On no occasion could symptoms of near-syncope be detected. Subjectively, all of these tests were exceedingly well-tolerated. Observation of the physical apearance while tilted showed a tendency to bluish mottling of the hands and feet and a tendency to increased filling of the veins of the legs.

Postflight results are shown adjacent to the preflight findings in table 18–XV and figures 18–7 and 18–8. It is readily evident that in the postflight tilt test no. 1 (conducted approximately 1 hour after landing) the mean pretilt heart rates were found to be 11 beats per minute higher than during the preflight controls, and the tilt produced a greater heart rate response than any of the preflight tilts. Most of the values from tilt test no. 1 were 120 beats per minute (maximum 132 beats per minute) and exceeded any of the maximum values obtained during the 11 preflight tilts. A Flack Test was not believed to be indicated in view of the tilt response. Tilt test no. 2, conducted 3 hours after landing and 2 hours after no. 1, began from a higher point and showed an even greater rate response; three of the six values were between 140 and 144 beats per minute. Within 4½ minutes after tilt, the heart rate had declined to 132 beats per minute when the Flack Test produced a jump to 145 beats per minute. The tilt was ended and subsequent rates were similar to the pretilt rates. Tilt test no. 3, conducted 6¾ hours after landing and 3½ hours after no. 2, showed responses very close to the preflight maximums, which are still excessive, but much less so than the previous two tilts. The rates decrease slightly after the Flack Test. Tilt test no. 4, initiated 19 hours after landing and 12½ hours after no. 3, produced responses very near those obtained before flight with a continued slowing of heart rate after the Flack Test. Unfortunately, simultaneous ECG could not be recorded with any of these tilts.

The blood-pressure responses to the postflight tilts were nearly uniform; therefore, only the mean values are shown in figure 18–8. Instead of the preflight systolic drop with prompt compensation and a 15 mm Hg diastolic rise following the tilt, most of the postflight tilts were followed by a systolic drop, a very delayed systolic rise, and little or no change in diastolic levels. Narrowing of pulse pressure to as little as 6 mm Hg was evident in the early postflight tilts. Table 18–XVI presents the postflight blood pressure values during the tilt studies.

The blood pressure responses to the final tilt were nearly normal but still showed a delayed compensation for the systolic drop. No visible objective changes occurred and there were no subjective symptoms.

In summary, the preflight tilt test produced expected cardiovascular compensatory reactions in that they could be demonstrated by heart rate, blood pressure, and ECG data, and all of these tests were well tolerated. The postflight tilt tests demonstrated the presence of moderate orthostatic hypotension, with far greater heart rates required to maintain effective cardiovascular function. Compensation was achieved, however, and the pilot did not develop even near-syncope. Tilt studies of responses after stresses similar to those experienced during flight are not available. Contributing stress factors including heat stress, the effect of prolonged confinement, dehydration, fatigue, and a possible effect of weightlessness per se are thought to be the principal elements responsible for this change. The picture is further clouded by residual effects of the dextro amphetamine.

#### Calibrated Work

A device for calibrated work consisting of a short plastic handle and expandable bungee cords (see fig. 18–9) was fixed within the spacecraft near the astronaut's feet. A limiting cable ensured repeatability of handle travel, requiring 65 pounds of force for each full extension. At 2:25:00 and again at 7:41:00 g.e.t, the astronaut recorded his blood pressure, pulled the device 30 times in as near 30 seconds as possible, and again recorded his blood pressure. The results of these two work periods were com-

*Table 18–XVI.—Blood Pressure Values During Tilt Studies, Postflight*

| Tilt | Pretilt | | Tilt | | Posttilt | |
|---|---|---|---|---|---|---|
| | Time | Value | Time | Value | Time | Value |
| May 16, 1963; No. 1 | 13:35:00 | 90/80 | 13:46:30 | 90/70 | 13:52:00 | 90/70 |
| | 13:36:00 | 90/80 | 13:46:45 | 86/70 | 13:53:00 | 94/72 |
| | 13:37:00 | 90/82 | 13:47:30 | 86/78 | 13:54:00 | 96/74 |
| | 13:46:00 | 88/76 | 13:48:30 | 86/70 | 13:55:00 | 98/78 |
| | | | 13:49:00 | 84/70 | 13:56:00 | 100/80 |
| | | | 13:50:00 | 84/70 | | |
| May 16, 1963; No. 2 | 15:42:00 | 86/60 | 15:44:00 | 100/70 | 15:51:00 | 104/72 |
| | 15:43:00 | 88/62 | 15:44:30 | 94/74 | 15:51:30 | 104/72 |
| | 15:43:15 | 88/64 | 15:45:00 | 84/78 | 15:52:00 | 106/74 |
| | 15:43:30 | 88/66 | 15:46:00 | 82/72 | 15:52:30 | 102/70 |
| | | | 15:47:00 | 92/84 | 15:53:00 | 104/72 |
| | | | 15:48:00 | [a]102/80 | | |
| | | | 15:50:00 | 86/60 | | |
| May 16, 1963, No. 3 | 19:11:00 | 88/52 | 19:15:00 | 110/68 | 19:19:45 | 92/58 |
| | 19:11:30 | 88/54 | 19:15:30 | 84/70 | 19:20:15 | 96/60 |
| | 19:12:00 | 90/52 | 19:16:00 | 80/68 | 19:21:00 | 92/60 |
| | 19:13:00 | 90/54 | 19:17:00 | 86/68 | 19:22:00 | 94/58 |
| | 19:14:00 | 88/54 | 19:18:00 | 80/74 | 19:23:00 | 92/58 |
| | | | 19:18:30 | [a]120/90 | | |
| | | | 19:19:00 | 80/70 | | |
| May 17, 1963; No. 4 | 07:42:00 | 96/60 | 07:45:30 | 92/78 | 07:51:00 | 96/56 |
| | 07:43:00 | 98/60 | 07:46:00 | 100/68 | 07:52:00 | 100/54 |
| | 07:44:00 | 100/62 | 07:46:30 | 88/68 | 07:53:00 | 100/56 |
| | 07:45:00 | 98/60 | 07:47:00 | 92/70 | 07:54:00 | 108/58 |
| | | | 07:48:00 | 92/66 | 07:55:00 | 104/54 |
| | | | 07:49:00 | 86/64 | | |
| | | | 07:50:00 | [a]110/64 | | |

[a] Values recorded during Flack Tests.

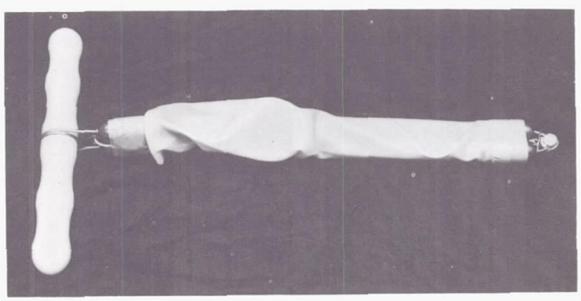


FIGURE 18–9.—Exercising device used for calibrated work.

paredwith five such periods performed at normal gravity in the spacecraft and in the procedures trainer.

Subjectively, the astronaut could tell little difference between the work performed under normal gravity and under zero gravity, the effort under zero gravity being, if anything, slightly easier. During flight he felt his postwork breathing was not as labored as it was following control runs, and he thought his heart rate returned to prework values more rapidly. The data, however, do not support this statement.

Analysis of the data does not show any striking differences between the one gravity and zero gravity work periods. Inflight mean heart rates during the calibrated work period are 16 beats per minute higher than preflight, but his inflight mean heart rate before work is 15 beats per minute higher. (Return to prework values was slower following the inflight exercise.) The results are given in table 18–XI and presented graphically in figure 18–10. One preflight heart rate during work was 160 beats per minute. This value occurred at the only time in one of the seven periods in which he worked

over 0.7 minute and probably reflects the prolongation of the work period rather than indicating a higher work load. During the 18-second recovery period after the test, the preflight mean heart rate dropped to 11 beats per minute over the preflight value, while during the flight it fell to 17 beats per minute over the prework mean.

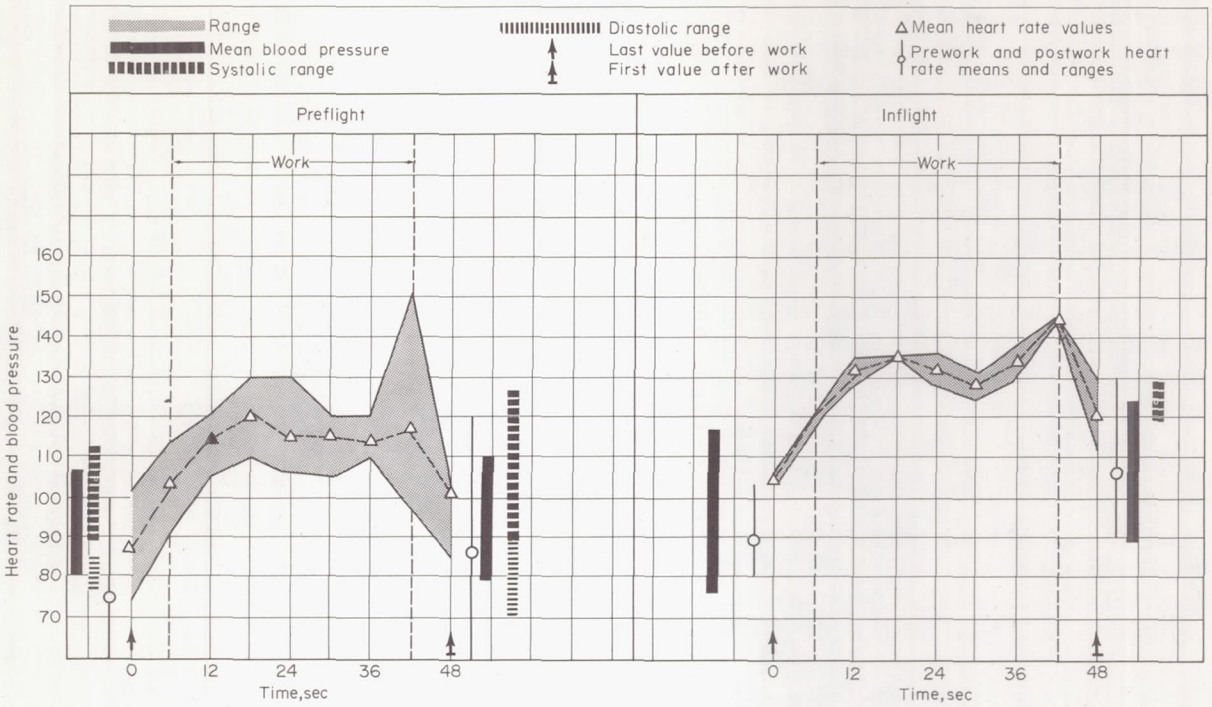



FIGURE 18–10.—Calibrated work—MA–9.

*Table 18–XVII.—Blood Chemistries*

| Determination | Mar. 12, 1963 | May 8, 1963 | May 12, 1963 | May 14, 1963 | May 16, 1963; landing +2½ hours | May 17, 1963; landing +24 hours | May 20, 1963 |
|---|---|---|---|---|---|---|---|
| Calcium, mEq/*l* | 4. 17 | 4. 28 | 4. 60 | 4. 22 | 4. 67 | 4. 56 | 4. 22 |
| Chloride, mEq/*l* | 105 | 106 | 100 | 104 | 104 | 102 | 104 |
| Protein (total), g/100 ml | 6. 0 | 6. 3 | 6. 0 | 6. 6 | 6. 3 | 6. 2 | 6. 2 |
| Phosphorus, mg/100 ml | 4. 2 | 3. 5 | 4. 4 | 4. 4 | 4. 5 | 4. 0 | 3. 4 |
| Sodium, mEq/*l* | 153 | 151 | 161 | 144 | 153 | 147 | 146 |
| Potassium, mEq/*l* | 4. 6 | 4. 6 | 5. 4 | 5. 2 | 5. 2 | 5. 0 | 4. 9 |

### Special Clinical Studies

Retinal photography, urine and plasma electrolyte determinations, and plasma enzyme studies comprise special clinical studies. The retinal photographs, taken after the flight for comparison with preflight pictures, show no changes. The results of the urine-electrolyte determinations are presented in table 18–V. The results of the plasma electrolyte determinations appear in table 18–XVII. It should be noted that mineral content of the diet was not provided in equal daily portions during the period of time represented by this table. There was no indication of increased urinary calcium excretion. Sodium and chloride retention shown on May 17 and 18 are consistent with the period of restoration of fluid balance following the dehydration which occurred in flight. All

other values are within the normal range for Astronaut Cooper. Enzyme studies have been made in each of the Mercury flights as part of a development program. The clinical significance of the data is still undergoing validation; therefore, interpretation has not been attempted. Consequently, results are not reported in this paper.

## Conclusions

On the basis of the total experience obtained during Project Mercury, the following medically significant facts have been derived from the medical operations.

(1) There has been no evidence of significant degradation of pilot function attributable to space flight. A mission of 34 hours in the zero-gravity condition has been well tolerated and all measured physiologic functions remained within anticipated ranges throughout this flight.

(2) Sleep in flight is possible and subjectively normal.

(3) The radiation dose received by the astronauts to date is considered medically insignificant.

(4) There is no evidence of abnormal sensory, psychiatric, or psychological response to an orbital space flight of up to 1½ days.

(5) Following missions of 9 and 34 hours duration, an orthostatic rise in heart rate and fall in blood pressure has been noted and has persisted for between 7 and 19 hours after landing. The changes were of greater magnitude following the 34-hour flight than those following the 9-hour flight; however, all changes disappeared in a similar time interval in both cases. The implications of this hemodynamic response will have to be given very serious consideration as longer missions are undertaken. No other clearly significant changes have been found in comprehensive preflight and postflight physical examinations.

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## References

1. Staff of NASA Manned Spacecraft Center: *Results of the Third United States Manned Orbital Space Flight, October 3, 1962.* SP–12, Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
2. Staff of NASA Manned Spacecraft Center: *Results of the Second United States Manned Orbital Space Flight, May 24, 1962.* Sp–6, Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
3. Staff of NASA Manned Spacecraft Center: *Results of the First United States Manned Orbital Space Flight, February 20, 1962.* Supt. Doc., U.S. Government Printing Office (Washington, D.C.).

# 19. OBSERVATIONS OF SPACE PHENOMENA

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## Summary

In the following report are presented the principal scientific observations made by the Mercury astronauts, arranged according to the sequence: daylight, twilight, and night. The first section is principally concerned with the examination of the earth as seen from these heights, although a section is also presented on the sky. In the second section, the appearance of the sun at sunset is discussed, then the twilight atmosphere, and the astronomical phenomena peculiar to the early twilight. In the third section are discussed the new data about the earth as seen at night and the difficulty associated with viewing the moon at the horizon.

## Introduction

From the beginning of time, man has looked out upon this world with an active curiosity, cataloging what he saw and eventually developing explanations for why the earth and sky appear as they do. The results of this type of naturalistic activity as they relate to the earth's atmosphere have been summarized by Minnaert (ref. 1), whose work summarizes at least the main lines of all of the knowledge which man had been able to gain from an earthbound position, by use of the unaided eye. With the advent of manned space flight, it is possible for the first time to observe the earth from outside the atmosphere, and so to extend the naked-eye observations which are summarized in Minnaert's work.

This section compiles and summarizes the observations of the Mercury astronauts and the findings from the principal photographic studies conducted during the Mercury flights. These observational and photographic data were limited by a number of operational constraints discussed in paper 12. The position, transmission polarization structure, and field-of-view of the spacecraft window are described in figure 19–1. As can be seen, this window contains two panes of plate glass and two panes of Vycor, the latter set at oblique angles, which increases the problem of light scattering and window reflections from internal lighting during night time observations. The window transmission cuts off sharply at the lower end of the visual spectrum, precluding photography in the ultraviolet region. Transmission in the infrared range permitted photography in this area for the Weather Bureau. Transmission in the visual range is reduced approximately to the same extent that light is attenuated by the atmosphere. The polarization produced by the window was probably of no significance to any of the observations described in this section. The field-of-view was a limiting factor since control fuel conservation restricted the freedom of the pilot to orient his vehicle for making observations. In addition to the viewing limitations indicated in figure 19–1, during the normal launch, the window frequently becomes covered with a film from the exhaust of the escape tower when it is jettisoned, which reduces slightly the light transmission and increases the problem of scattering.

Throughout this portion, an attempt is made to present an integrated picture of the appearance of the earth and sky as viewed from space, together with a physical explanation of the phenomenon observed where sufficient information is available to make hypothesis. In general, most of what has been reported by the astronauts confirms data from other sources, such as recent aircraft, balloon, and sounding rocket studies. If much of the information is not novel, it has helped to fill in the basic outlines

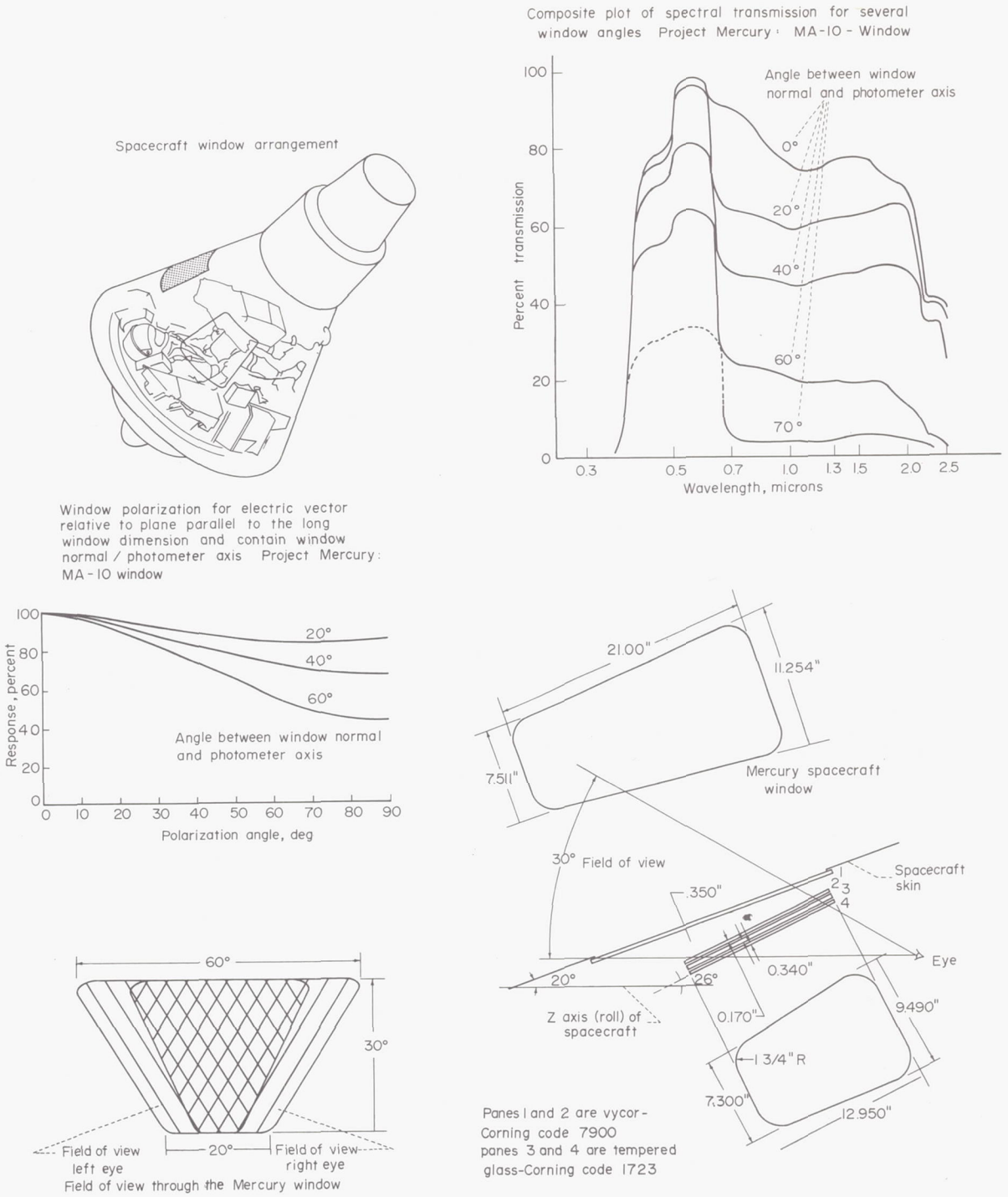



FIGURE 19–1.—Mercury spacecraft window.

of our knowledge about many features of the upper atmosphere.

The program of astronaut observations and their interpretation has been greatly aided by consultation with investigators in a number of fields. The individuals who consulted with Manned Spacecraft Center personnel on the science program are listed at the end of this section.

## Appearance of the Earth in Daylight From Space

During the daylight phase of the orbit, the general impression of the earth as seen from a

distance of 100 to 150 miles has been characterized by the astronauts as similar to the view from a high-flying jet aircraft. The earth's surface, particularly when viewed obliquely, appears to have a somewhat bluish cast, as would be expected from the longer visual path through the atmosphere. Greens are less readily visible, except when directly below the spacecraft. However, major color variations can be distinguished. The coastlines and rivers are easily visible (fig. 19–2) as are mountain ranges (fig. 19–3).

In the daytime, the clouds are extremely bright and easily visible. The astronauts have reported that, generally, they can determine relative cloud levels, perhaps by noting shadows or the apparent motion of cloud tops relative to the surface. Different types of cloud formations are relatively easily discernible. These may be quite spectacular as when the spiral shape of a hurricane a thousand miles in diameter is clearly seen from above (fig. 19–4).

The day horizon has been described as a light-blue band, shading off into the blackness of the space above the earth. Photographs taken by the astronauts provide some indication of banding in this horizon layer. Such banding has been reported by Astronauts Shepard, Grissom, and Glenn in references 2 to 4, respectively. The banding appears to be related to the layers in the atmosphere. The width of the daytime horizon appears to correspond to the width of the troposphere and to be approximately ½° as viewed from the spacecraft. This is demonstrated in figure 19–5, which shows the moon just above the daylit horizon. The diameter of

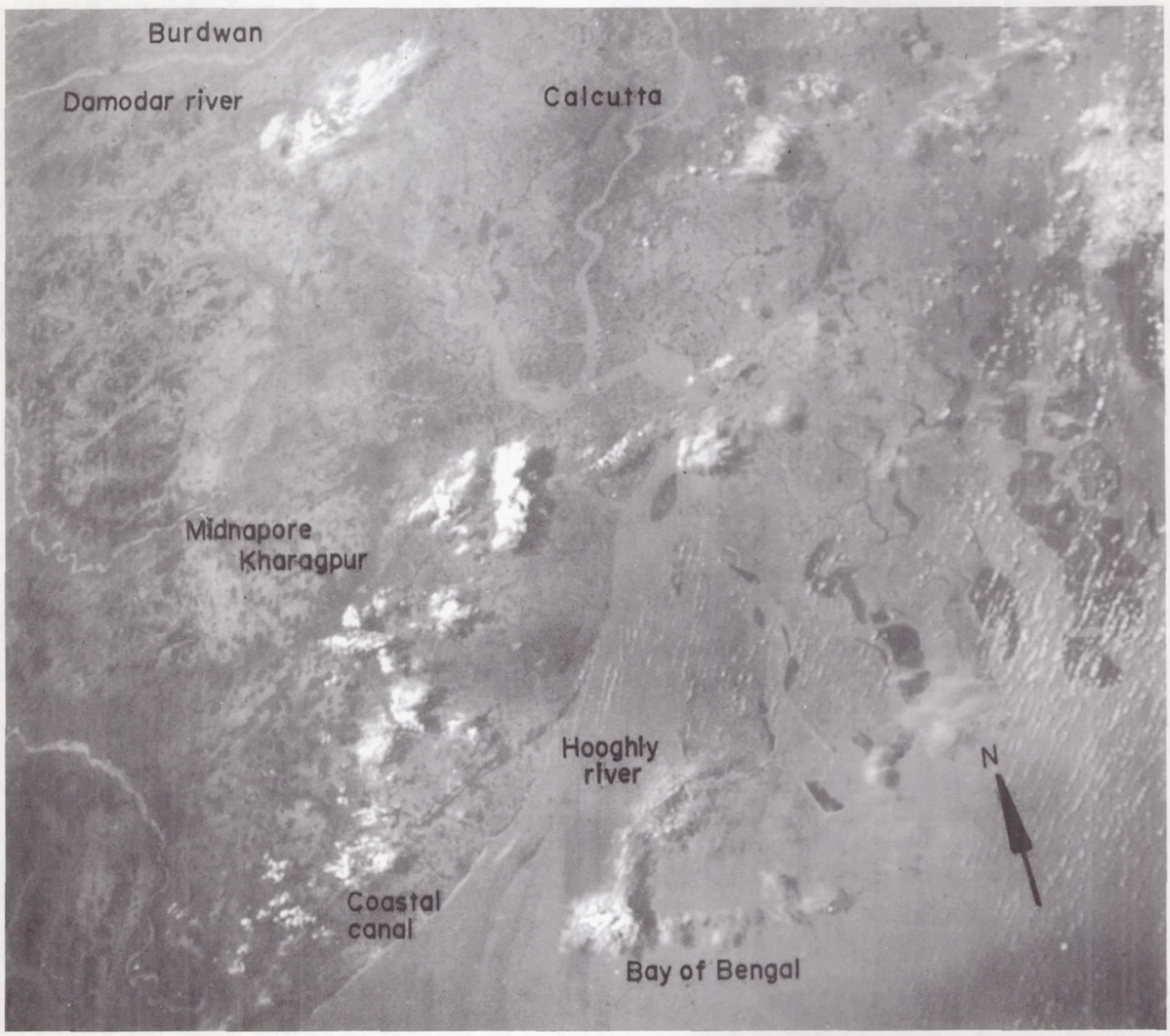



FIGURE 19–2.—Ganges River Basin. MA–9 photograph.



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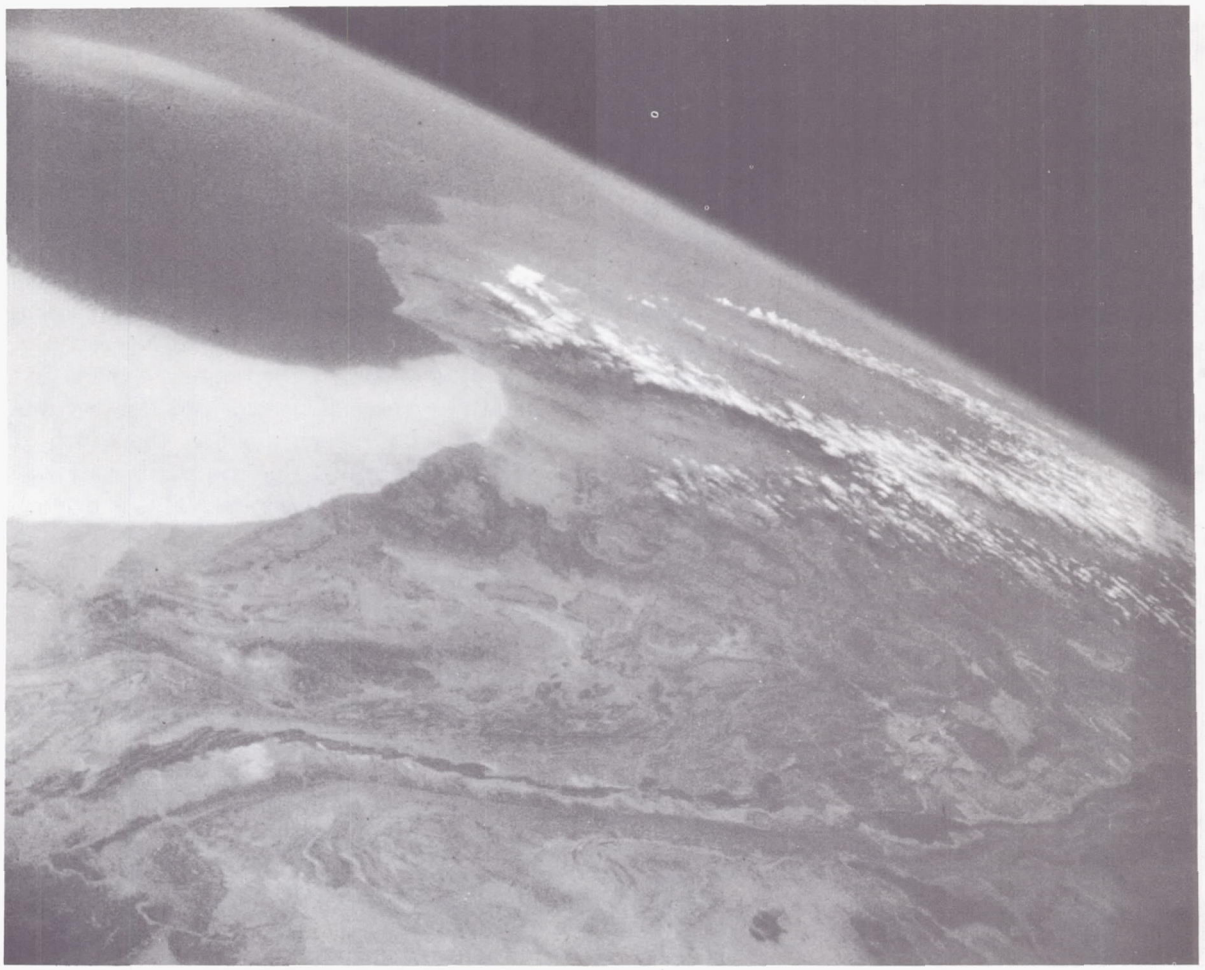


FIGURE 19–3.—Anti–Atlas Mountains in North Africa. MA–4 photograph.

the moon, which is ½°, is approximately equal to the thickness of the daytime horizon as pictured in the photograph.

### Visibility of Ground Features

The visibility of small features on the surface of the earth from space is a complex but important problem since ground landmarks offer a potentially very useful navigational reference. To obtain some information on the operational problems of viewing objects on the surface of the earth in addition to that provided by the ground light study reported in the section on experiments, the pilots were asked to report carefully what could be seen from orbit. These observations have been described in the pilot's report made after each manned flight.

One of the major features of interest to Glenn during the MA–6 flight (ref. 4) was the extent of the cloud cover over the earth. The only area that has been consistently clear throughout all the orbital flights is the western African desert shown in figure 19–3 and the southwestern United States. Efforts to observe ground signal lights from the spacecraft were frustrated on three of the four flights by overcast conditions (See paper 12). Astronaut Cooper enjoyed the best visibility conditions of any of the astronauts and yet he estimated the cloud coverage to average 50 percent during his flight.

Even where no cloud coverage is present, visibility may be markedly deteriorated by haze produced by smoke, dust particles, or other aerosols. Thus, for example, Astronaut Cooper noted that, while he could see roads and fields and an airport in the El Centro area, he could not see either Los Angeles or San Diego, though he flew right over them. Figure 19–2, which shows a view of the Ganges River Basin photo-

graphed on the MA–9 flight, demonstrates this problem since the city of Calcutta with 2½ million population is almost completely invisible and was not seen by Cooper during the flight. Landmarks can be most clearly seen when viewed directly below the spacecraft. The blue haziness, which is seen in photographs of the daylight horizon (fig. 19–5), illustrates the reduction in visibility produced by the longer path through the atmosphere. The visibility of features farther from the spacecraft is also reduced by the reduction in size because of viewing distance and foreshortening because of the angle-of-view and the earth's curvature.

Moreover, cloud cover may not simply obscure targets. It may also produce cues which lead to misinterpretation of terrain features. An example of this is shown in the photograph in figure 19–3, taken on the MA–4 flight, which shows a low lying cloud over the Atlantic coast of North Africa. The position of the cloud produces an apparent change in the coastline, which could be confusing if such geographical features were to be used for navigation.

Thus, the extent of cloud cover and atmospheric haze in the latitudes in which the Mercury flights have been made reduces the usefulness of landmarks or ground lights for navigation. On the other hand, in areas where the weather is good, relatively small objects may be sighted. However, this is not a result of magnification produced by the difference in refractive index between the atmosphere and the vacuum of space as had been proposed in reference 5. The effect proposed is the same as the magnification of a penny at the bottom of a cup of water—the penny appears to be a little higher than it really is (fig. 19–6). Because of the relatively small difference between the refractive index of the atmosphere and the vacuum,

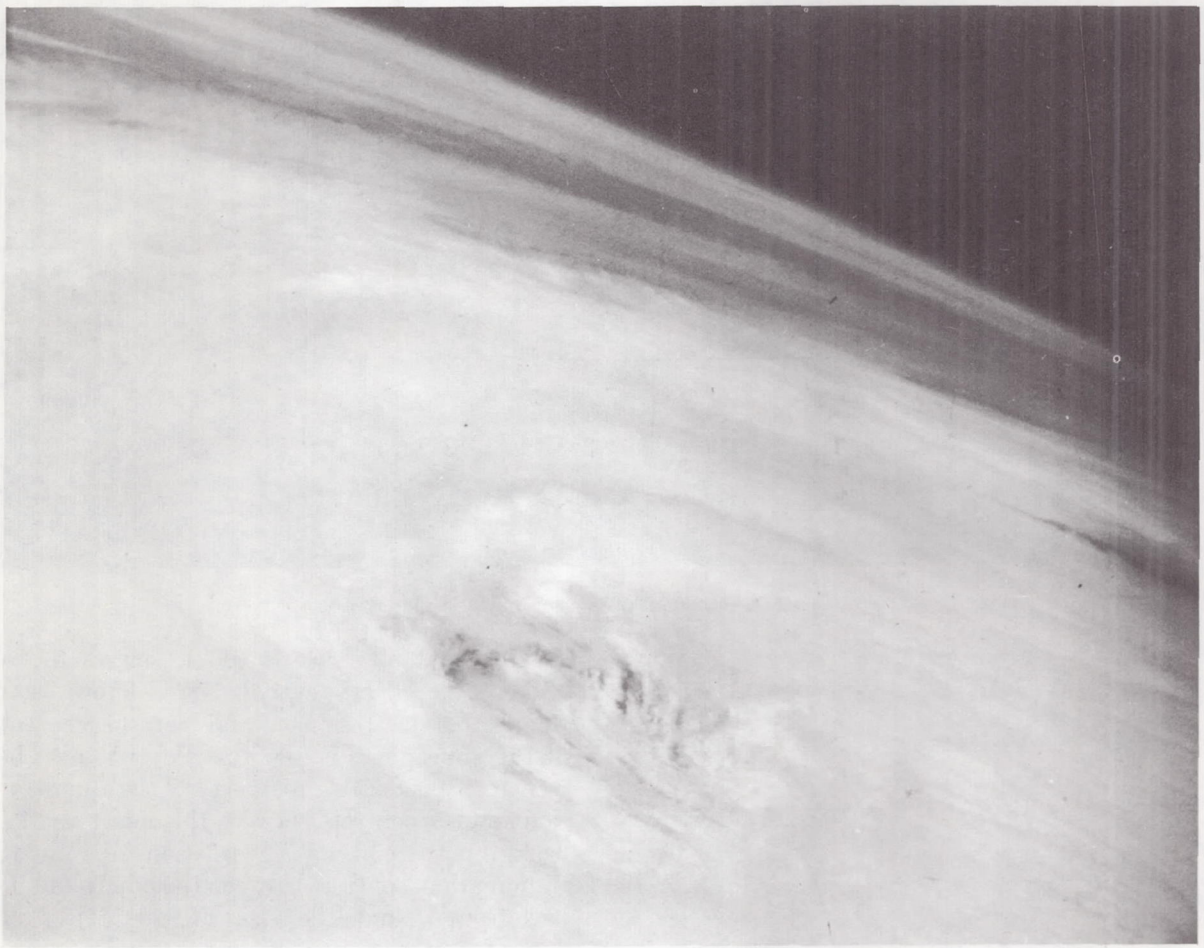


FIGURE 19–4.—Hurricane Debbie. MA–4 photograph.

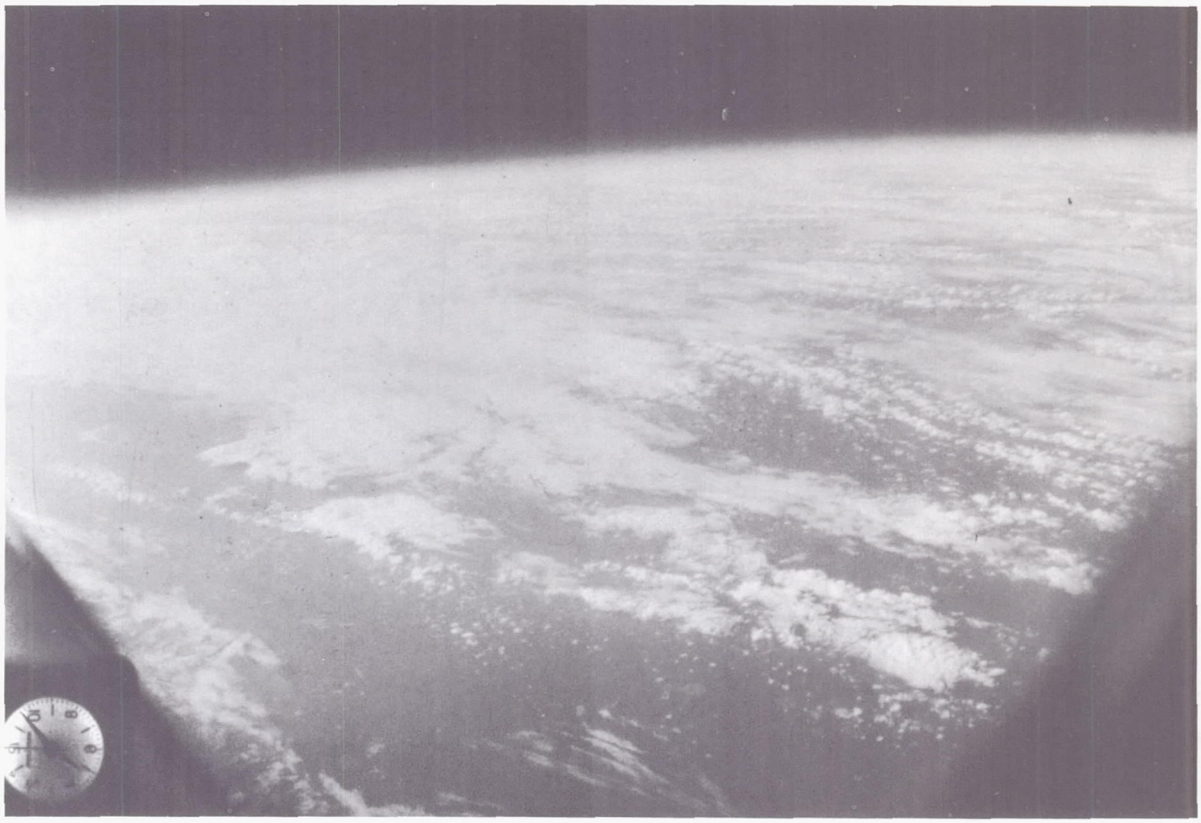


FIGURE 19–5.—Moon near horizon. MA–5 photograph.

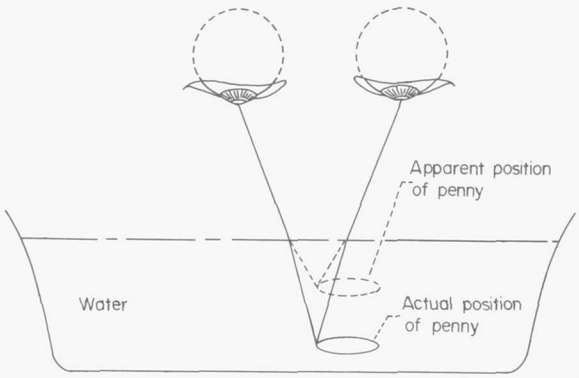



FIGURE 19–6.—Diagram of apparent magnification produced by water.

the effect is much smaller than in water. If the index of refraction is computed and summed for each kilometer of atmosphere up to the altitude of 45 kilometers (where it becomes unity) based on the *U.S. Standard Atmosphere, 1962*, the maximum magnification possible is on the order of only 1.00002, or a rise of 8.5 feet.

The problem of visibility from aircraft has received considerable attention in recent years (ref. 6). This work is too extensive to be reviewed here. However, it is well known that where the dust, smoke, and aerosol content of the atmosphere is low, small objects may be seen for considerable distances if the illumination and the contrast between the object and its background are high. The relationships among illumination, contrast between the object and its background, and the size of the object or angle subtended at the eye is indicated in figure 19–7. These data, taken from the well-known work of Blackwell (ref. 7), illustrate that the smallest object that can just be detected 50 percent of the time is dependent on size contrast and illumination. One minute of arc is often taken as a "rule of thumb" for the practical limit of human visual acuity. However, as can be seen from this figure, this is an oversimplification. Under many combinations of illumination and contrast, the smallest object that can just be seen is 10 times that large, while at other combinations of these factors, objects approximately ½′ of arc can be seen. Where contrast or illumination are very high, even smaller

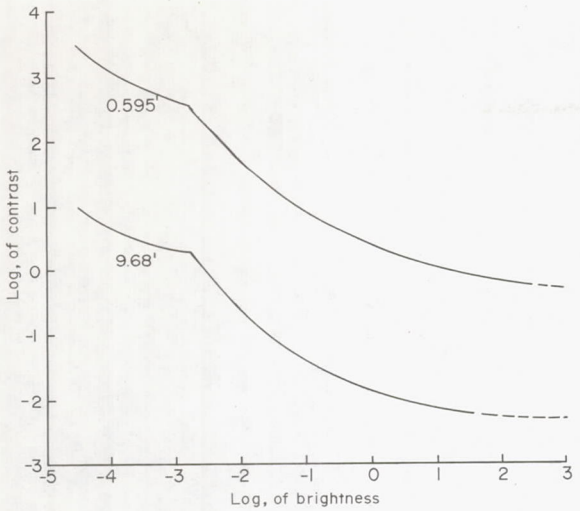



FIGURE 19–7.—Threshold of brightness contrast for 50 percent detection for two stimuli diameters (minutes of arc), after Blackwell (ref. 7. Stimuli brighter than background. Unlimited time of exposure.

objects may be seen. Thus, Zoethout (ref. 8) gives a value of 10″ of arc for the minimum visible white square on a black background. This corresponds to 30 feet at 100 nautical miles.

These general relationships are complicated by several factors. Thus, for point light sources, such as stars, visibility is independent of size and dependent only on the intensity of the stimulus. For line or ribbon objects, the extended length reduces the necessary diameter for detection, thus the width of a line, which can just be detected, may be one-sixth or less than the minimum diameter of a circular object which can just be seen. This is illustrated in figure 19–8 which shows an infrared photograph taken by a Viking rocket over the southwestern United States (ref. 9). This photograph was taken at a height of 150 miles. From the type of film, the characteristics of the camera lens, the exposure length, and the extent of enlargement, the resolution can be calculated to be 500 feet (ref. 10). Yet roads running across the desert, whose width must be on the order of 50 feet or less, can be clearly seen.

There have been several reports by the astronauts of sightings of small objects on the daylight side of the orbit. These observations have primarily been confined to the area of the southwestern desert of the United States between El Centro, California, and El Paso, Texas. In this region, cities, cultivated fields, roads, airports, and railroads have been reported by all four of the pilots who flew orbital flights. These observations have all been made at close to perigee altitude (86 to 90 nautical miles) between 8:00 and 12:00 a.m., local time, under excellent visibility conditions. Astronaut Cooper, who enjoyed unusually good weather conditions, also reported identifying the cities of Dallas and Houston, in Texas, and from the pattern of lakes and wooded areas, the region around Clear Lake where the new Manned Spacecraft Center is being built. In addition, the astronaut made a number of observations in the mountainous and plateau regions of India and Tibet. There he reported what appeared to be individual buildings in Tibetan villages. Some of these observations were apparently aided by trails of smoke from the chimneys of the buildings. In addition, he reported he was able to see roads on one of which he saw a trail of dust. At the intersection of the dust trail and the road, he saw a spot which he felt might be a vehicle (See paper 20). These observations over Tibet were made from an altitude of 88 nautical miles at approximately 7:30 a.m., local time. The weather conditions were clear with good visibility. Atmospheric attenuation was further reduced by the altitude of the Tibetan plateau which at this point is approximately 16,000 feet.

It should be recognized that all these observations were greatly facilitated by the context in which the observation was made. To be reported, objects must be perceived. Previous training and experience have a marked effect on what an individual will report in any situation. Experience generally increases the likelihood that a small object near visual threshold will be detected, although it may work in the opposite direction as when an unusual angle of lighting or shadow changes the appearance of an object to the point that it goes unrecognized. Such experience and training can also lead to the accurate identification of objects that would otherwise not be recognized. This procedure is much like that of interpretation of a photograph where a set of vehicle treadmarks, running into a forest area, indicate the possible presence of a vehicle among the trees.

Astronaut Glenn described a situation in which he saw a road crossing a river. Each of these could be recognized because they were extended, ribbon-type objects. At the point

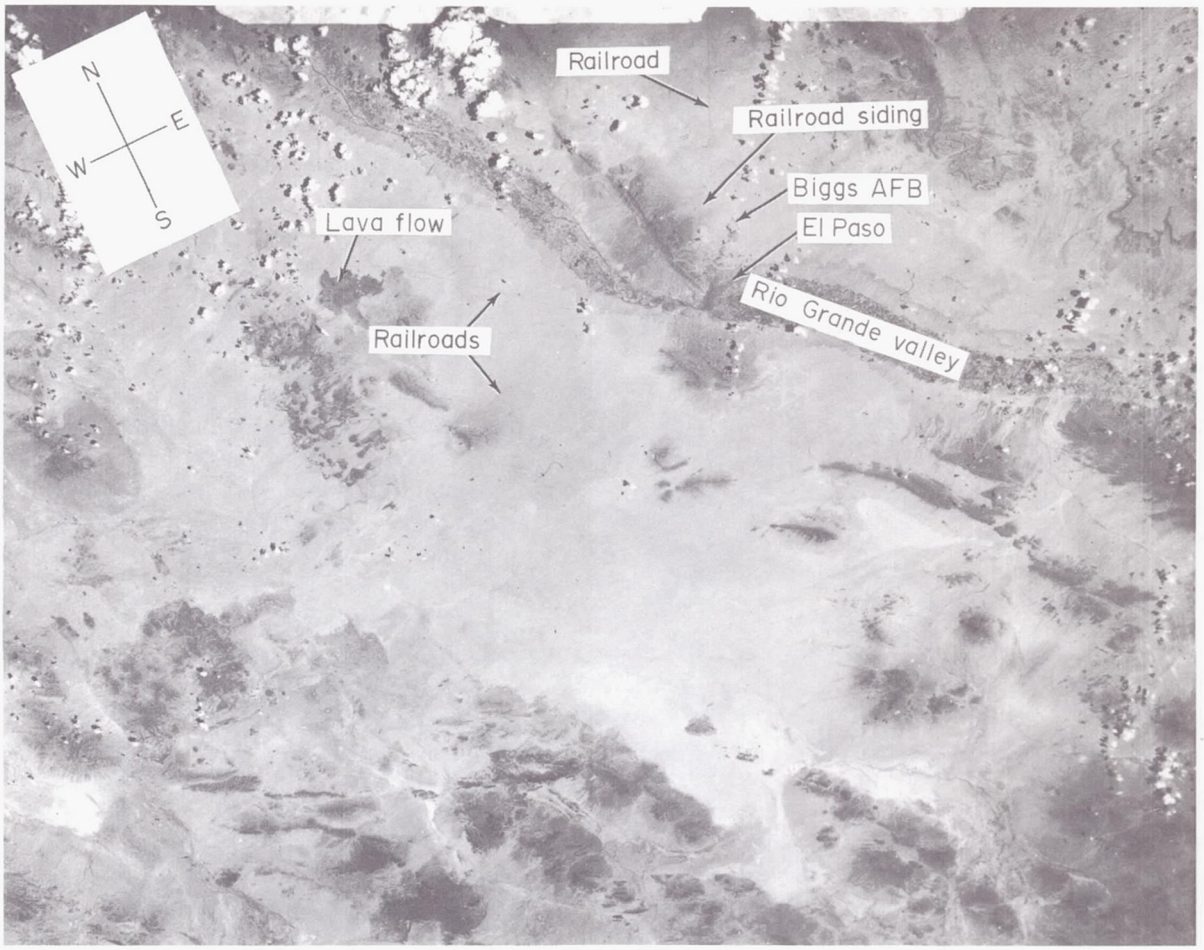



FIGURE 19–8.—Viking photograph of El Paso, Texas, area.

where they crossed, he said that he felt he could almost see the bridge, though he recognized that it was too small to be seen.

Since the actual objects which were being viewed at these points cannot be verified, it is not possible to determine the accuracy of these observations. However, from knowledge of the factors which affect visibility under these conditions, there appears to be no reason to suspect that these identifications were not generally accurate. All the astronauts have normal, or better, distance visual acuity. Astronaut Cooper in particular has an acuity, as measured during a recent annual physical, of 20/12, which is significantly better than 20/20 which is the normal standard of good acuity. All the observations were made under high levels of illumination, excellent visibility conditions, and with the aid of many contextual cues. Thus, there appears to be no need for postulation of either improved visibility resulting from weightless conditions or unexpected atmospheric magnification effects to account for the observations made to date. Despite the impressive nature of these observations, the important feature to be kept in mind is that they are scattered and involve viewing under essentially optimal conditions. As pointed out earlier, the large amounts of haze and cloud cover make ground observations difficult and somewhat unreliable.

### Terrain Photography

As with the problem of direct viewing, it is not possible to put a lower limit on the physiographic and geologic detail which can be delineated on space photographs without an extensive study. However, a rough idea of the useful resolution can be gained by examination of some of the Mercury pictures listed in table

*Table 19–I.—Summary of Potential Usefulness of Mercury Earth Photographs*

| Flight | Area covered | Film type | Approximate number useful pictures | Potential uses and remarks |
|---|---|---|---|---|
| MR–1 | AMR | 70 mm, black and white | 168 total | Meteorology |
| MR–2 | AMR, Florida, Bahamas | 70, mm, color | 30 useful | Meteorology and topography; good quality |
| MR–3 | AMR | 70 mm, color | 50 feet exposed | Meteorology; relatively poor quality |
| MA–4 | Atlantic Ocean, North Africa | 70 mm, color | About 350 usable photographs | Meteorology, topography, and geology; excellent quality |
| MA–5 | Florida, West Coast, Mexico, Ocean areas | 70 mm, color | 80 feet probably about 5 to 10 usable terrain photographs | Meteorology, topography; fair quality |
| MA–6 | Florida, North Africa | 35 mm, color | 38 usable pictures, about 5 or 6 terrain photographs | Meteorology, topography, geology; good quality |
| MA–7 | West Africa | 35 mm, color | 200 pictures, 4 or 5 terrain photographs | Meteorology, topography |
| MA–8 | Mexico, South America | 70 mm | 14 color photographs | Fair to poor quality; meteorology; quality of terrain pictures poor |
| MA–9 | Tibet, South east and South Central Asia, Africa, Middle East | 70 mm | 30 photographs | Meteorology, topography, geology; excellent |

19–I. This table summarizes the general purpose photographs taken on manned and unmanned Mercury flights.

The MA–4 photographs of North Africa are of considerable interest because they are among the best color pictures showing unobscured terrain. The Anti-Atlas Mountains are especially striking (fig. 19–3) in the amount of geologic detail which can be seen. The folded structure of the mountains is obvious, and many individual plunging folds can be traced. A linear feature suggestive of the Zemmour fault (ref. 11) can be seen intersecting the coast south of Agadir but not identified with any certainty.

Many of the MA–9 photographs show abundant topographic and geologic detail. Figure 19–9, taken over the Tibetan plateau, is particularly useful because of the favorable camera angle. A geologic sketch prepared from this photograph is shown in fig. 19–10. A number of structures of possible economic interest are indicated in the sketch. For example, the domes and anticlines represent potential oil-bearing areas, and intersections of some of the lineaments might be the loci of mineral deposits.

It is interesting to note that manmade features (excepting large areas of cultivation) are generally very difficult to identify on the color photographs. As already noted, figure 19–2 shows the area of Calcutta but the city itself cannot be recognized.

The scientific value of the Mercury terrain photographs depends on several characteristics in which they differ from conventional aerial



FIGURE 19–9.—Photograph of Tibetan Plateau. MA–9 photograph.

photography. The most obvious of these is the tremendous aerial coverage provided by each picture taken from orbital altitude. This is illustrated by comparison of the 1 : 800,000 scale of figure 19–9, taken on the MA–9 flight, with the 1 : 20,000 or 1 : 40,000 scales of conventional air photos. The area covered increases with approximately the inverse square of the scale, and is so much greater in pictures taken from space as to be virtually a qualitative difference. This great coverage permits continuity of observation which may lead to discovery of large geologic features unnoticed on conventional photographs, such as the very long lineaments illustrated in figure 19–10. It should also be mentioned that the synoptic nature of space photography is valuable in meteorological and oceanographic applications.

Another characteristic of space photographs is the fact that they show the earth, subject to limitations of visibility and resolution, as it is. Stereoscopic vision is possible with even roughly oriented photographs if there is overlap. In addition, subtle tonal differences covering large areas can be detected. Both of these properties are essential for geological interpretation and




FIGURE 19–10.—Geologic sketch based on figure 9.

cannot, in general, be provided by mosaics of conventional aerial photographs. This strongly suggests the unique scientific value of terrain photographs from orbital altitudes, not only for unexplored areas such as Tibet, but also for areas previously covered by conventional photography.

In sumary, photographs of the earth from orbiting spacecraft are potentially valuable for (1) geologic reconnaissance, (2) topographic mapping, (3) forest mapping, (4) icepack and iceberg monitoring, (5) supplemental weather observations, and (6) mapping of near-surface ocean currents. In addition, experience in interpreting such photographs will prove useful in interpreting similar photographs of the planets when they become available.

#### Meteorological Information From Mercury Flights

Each astronaut has devoted part of his spaceflight program to visual and photographic observations of value to meteorology (ref. 12). Since high photographic contrast is needed in pictures from weather satellites to aid in distinguishing coastlines and patterns of thin clouds, two photographic studies were initiated to study cloud, land, and water contrast as a function of wavelength. These studies have been described in paper 12.

Astronaut Schirra took a series of 13 black and white photographs of the earth through six color filters in the visible spectral region from 3700 Å to 7200 Å to record some of the spectral reflectance characteristic of clouds, land, and water areas when viewed from outside the atmosphere. In general, the results from this study showed that, as would be expected, photographic contrast increases with increasing wavelength in the visible spectrum.

It might be concluded that the optimum wavelengths for viewing the earth would be in the near infrared spectrum where scattering from atmospheric particles is relatively low. That this is not quite true was demonstrated in a second study conducted by Astronaut Cooper. In this study, three areas of the infrared spectrum were isolated by use of filters and infrared film.

Water has a very low reflectance in the near infrared, while clouds and land have a high reflectance. Therefore, in this second study, coastlines and cloud patterns over water were easily discernible. Unfortunately, however, clouds were more difficult to see over land in the near infrared because of the high reflectivity of both clouds and areas covered with green vegetation containing chlorophyll.

These two studies show, then, that the spectral sensitivity of television camera systems for weather satellites should probably be restricted to the region from about 5000 to 7500 Å as a compromise between the adverse effects of scattering by molecules and aerosols at shorter visible wavelengths and the low contrast effects of clouds over land areas at near infrared wavelengths.

Many of the black and white pictures taken by Astronaut Schirra show a bright band on the earth's horizon. The bright band is approximately 16 kilometers thick, which agrees with the expected thickness of the tropical troposphere. Large light scatterers in the troposphere, such as dust and water droplets, produce this bright band at the earth's limb. The thermal stability of the stratosphere severely limits the convective transport of aerosols to higher levels, so that there is very little scattered light coming from the stratosphere. The apparent brightness of the tropospheric layer varies from picture to picture, suggesting that there are changes in the size or concentration of scatterers over different geographic areas. Changes in brightness in the same picture from one filter to another demonstrate the wave length dependence of the scattering of sunlight; more light is scattered at the shorter wave lengths. However, within an individual picture, both geographical and wave length effects may appear.

The pictures obtained with photographic film contains more meteorological information than do the low resolution pictures from present weather satellite television pictures. Because of the greater resolution and lower altitude the cloud types and patterns can be seen in greater detail in the Mercury photographs. If a meteorologist can see the smaller cloud forms and their orientation, then he may have important clues to the direction of the wind, the wind shear, and possibly a rough estimate of the wind speed in the lower levels of the atmosphere. Photographs from Mercury flights have been useful in cloud studies to help interpret the meteorological information in Tiros pictures.

Several Mercury astronauts have seen lightning in thunderstorms at night, appearing, as Astronaut Glenn described it, "like balls of cotton illuminated from within." Astronaut Cooper observed that each lightning flash was accompanied by static on his high frequency and ultrahigh frequency radio receivers. This observation confirms the findings of a recent research study conducted for the Weather Bureau, which concluded that high frequency energy radiated from a lightning stroke can propagate and be detected and located on a worldwide basis by means of a lightning (or sferics) detector carried on a satellite. Efforts are underway now to develop such an instrument and our confidence that it will work is much higher because of Astronaut Cooper's alert observation.

Cloud systems were visible at night with partial moonlight or none, indicating that low-light level television cameras on weather satellites may photograph cloud cover at night successfully. Photographs of clouds over snow are being studied to seek ways of discriminating one from the other in television pictures. Cooper reported he could detect the difference between snow and clouds. He also reported that smoke trails gave an indication of surface wind direction.

### Daylight Sky

To date, none of the astronauts has reported seeing stars on the daylight side when the sun or the illuminated earth's surface was within the field of view. Nor was the flashing light released from the MA–9 spacecraft seen by Astronaut Cooper during the daytime, though the possibility that he was looking in the wrong direction cannot be ruled out (See paper 12). However, some of the astronauts have reported observations of a few bright stars or planets at twilight, but their level of dark adaptation and the degree of cabin lighting are uncertain factors to be considered. There is, of course, no difficulty in seeing the moon (fig. 19–5) since it is even visible from the surface of the earth in daylight.

When the sun and the illuminated earth's surface is not within the field of view, it is possible to look into space and maintain dark adaptation. Under these conditions, Astronaut Cooper reported that the dayside sky appeared less dark than the night sky, and the threshold of star visibility correspondingly raised by as much as two magnitudes. Two hypotheses suggest themselves to account for this observation. The more probable one is that this results from a high altitude dayglow possibly that of the atomic emission at 6300 Å.

A second less likely hypothesis is that the sky appears less dark during the daytime as a result of scattering due to small solid particles. The argument against this proposal is as follows. If the glow were due to small solid particles, they would have to be at a level low enough so that the sun could not reach them during the night; otherwise, this glow would be apparent from the ground all night long. Since astronomical twilight is defined by saying that at the end of astronomical twilight the zenith has reached full night-time darkness, it is clear that at this time, the dust particles, if any, must be out of the sunlight. It is known that astronomical twilight occurs when the sun is 18° below the horizon; and it is a matter of simple trigonometry to show that at this time an object more than about 350 kilometers high would still be in the sunlight. Hence, if there is a layer of dust particles, they must be below 350 kilometers.

Now, Astronaut Cooper reports that the dayglow as he saw it drowned the light of stars fainter than about the fourth magnitude. This is about the same thing that happens on a night of full moon; the fifth and sixth magnitude stars become very difficult or impossible to see. Hence, the brightness of the sky as Astronaut Cooper saw it was more or less like the brightness of the sky on a night of full moon. We know that from the ground the sky causes a loss of about 30 percent in the light reaching the earth; and, thus, we may think of it as if there were small particles covering about one-third of the sky. Above the spacecraft, the sky is so much reduced in scattering power that it scatters only as much light from the sun as the whole atmosphere scatters from the moon. Since the full moon is about 400,000 times fainter than the sun, it follows that the amount of scattering material must be such as to cover about 0.3 of 1/400,000 of the sky, or roughly, one millionth. By the usual laws of optics, this means that in a column one square centimeter in cross-sectional area and 350 kilometers in

length, there must be enough matter to cover one millionth of a square centimeter.

It will be shown that this is too much matter. The most efficient size of particle for producing scattered light is about 1 micron in diameter; smaller particles perform the electrical equivalent of bobbing up and down on the light waves without disturbing them, and larger ones simply block the light. A 1-micron particle blocks about $10^{-8}$ square centimeters; hence about 100 such particles are needed in the above-mentioned column. Since the volume of the column is 35 cubic meters, the density is about 3 particles per cubic meter.

A spacecraft moving at 8,000 meters per second will then encounter 24,000 such particles per second per square meter. Actually, however, micrometeorite counters, which are adequately sensitive for these very small particles, show between 1/100 and 1 particle per second per square meter outside of showers. Rates of thousands of particles per square meter per second are never observed (ref. 15). Hence the layer cannot consist of micron-size particles. Neither can it consist of particles of other sizes, because the counts are even lower for these. There is approximately the same amount of mass in each logarithmic increase in size; and the other sizes are less efficient. The hypothesis of a dust layer thus fails by a factor which can be conservatively estimated as 10,000.

## Appearance of the Earth at Sunset and Twilight

The spacecraft window attentuates the average light intensity in the visible range to about the same extent as the atmosphere. It does not, however, produce the same color change. To the astronauts, the sun appears white; they describe it as having the color of an arc light, rather than the yellowish color seen from the earth. As the sun approaches the horizon, a band of orange light spreads from below the sun around the horizon. Above this orange band can be seen the hazy blue layer similar to that of the daytime sky. As the sun comes closer to the horizon, a white layer appears above the orange band. The orange, white, and blue layers are quite distinct, particularly the border between the white and blue layers. Some astronauts have been able to report on layers which do not appear in photographs. The orange, white, and blue layers, however, show up very clearly in the photographs of the setting sun and of the orbital twilight which follows.

As the sun approaches the horizon, the terminator passes below the spacecraft and moves off toward the horizon so that, at sunset, the earth directly below the spacecraft is dark. All that can be seen is the band of light in the west, stretching perhaps as much as 180° around the horizon.

The sun, of course, sets much more rapidly for the astronaut than for the observer on the ground. Since the sun moves for the ground observers at approximately 15° an hour, neglecting the effects of atmospheric refraction, it takes the sun, which is ½° in width, 2 minutes to set from the time it first touches the horizon to the time when it completely disappears. In contrast, for the orbital vehicle, the sun moves at 4° per minute so that, once again neglecting the effects of refraction, it sets in 7½ seconds. Once the sun has set, the glow along the western horizon gradually fades but remains visible for apparently about the astronomical twilight period or until the sun is 18° below the horizon, which is approximately 4½ minutes at orbital velocity.

### Solar Flattening Effect

Just prior to sunset, calculations show that the effects of terrestrial refraction should be to give the sun a football-shaped appearance. The phenomenon lasts such a brief time and is so extremely difficult to observe because of the problem of glare that only the visual report from Astronaut Carpenter (ref. 16) conclusively confirms it. It is, however, plainly visible on photographs, obtained by both Carpenter and Glenn (fig. 19–11), and matches the theoretical shape (ref. 17). The significant point here is not that the path of the ray through the atmosphere is different from the path as seen from the ground. Actually, the distance between the observer and the refractive layer causes the entire atmospheric effect to be compressed in such a way that it results in a completely different phenomenon.

### Twilight Bands

During twilight, three atmospheric layers at least are distinguishable (fig. 19–11). As illustrated in figure 19–12 at the top of the atmos-



FIGURE 19–11.—Sunset photograph. MA–7 photograph.

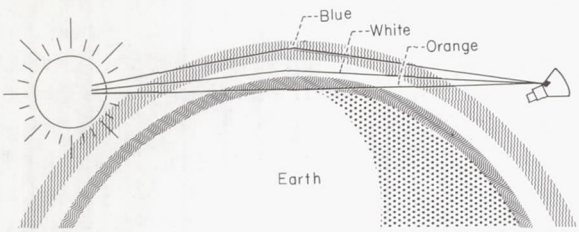



FIGURE 19–12.—Proposed explanation for horizon bands, seen at twilight from space.

phere, the light of the sun is scattered in the ordinary way (Rayleigh scattering) by atoms and molecules of the upper atmosphere. This layer is blue for the well-known reason that Rayleigh scattering varies as the minus fourth power of the wavelength and, therefore, effects the shorter blue wavelengths much more than the longer wavelengths. Lower in the atmosphere the scattering approaches saturation in all wavelengths, and so we have a white layer because there is enough atmosphere to scatter even the red light. Close to the horizon the brightness of more distant atmospheric layers exceeds that of the layers at which we are looking. As a consequence, we see, not the light which has been scattered by the atmosphere but that which has come through it either from the sun itself or from bright layers. As a result, this layer appears red, since the beam which reaches us has lost blue light.

Volz and Goody have studied the colors of twilight as seen from the ground (ref. 18). They find that in the rare cases when there are no storms between the observer and the sun, the twilight colors change slowly and continuously. Discontinuous changes occur when the contribution to the sky which should be made by some distant region is blocked by a storm. In the same way, if there were no storms along the line of sight as seen from the spacecraft, it would be reasonable to anticipate that the colors of the twilight horizon band would melt uniformly into each other. In general, however, just as the storms interrupt the orderly time sequence of colors as seen from the ground, so also they may interrupt the orderly spatial display of colors as seen from space in the twilight horizon band. In addition, the variation between troposphere and stratosphere may play a part in producing these lines.

In addition to these bands, which can be seen on photographs taken at twilight by Astronauts Glenn and Carpenter, Astronaut Schirra noted further detail in the area in and below the Rayleigh scattering level. He observed the planet Mercury setting through this region and reported a dark-blue band, a light-blue band, and then a dark-blue band near the earth's surface. These observations are still being analyzed; however, there is some indication that the Chappus absorption bands of ozone may play a role in producing the central blue band (ref. 19). Copper confirmed these observations of Schirra by describing the appearance of the blue banding and by examining a sketch prepared from Schirra's report.

### Luminous Particles

On numerous occasions, when the sun was above the horizon, small luminous particles drifting generally backward along the spacecraft line of motion at relative velocities of a few meters per second were observed by the astronauts. Carpenter demonstrated by rapping on the hatch that such particles could be produced from the spacecraft itself. Given the very close coincidence in orbit velocity, which is implied by the small relative velocity, it is considered highly probable that all such particles originate from the spacecraft. From the remark of Glenn that the particles seemed to be about as luminous as fireflies, it is possible to estimate that the sizes of those seen by him are of the order of one millimeter (refs. 20 and 21). Some of them may have been bits of debris. The majority, however, appear to be ice crystals probably formed from the steam which is released by the life-support system.

Astronaut Cooper (paper 20) reported seeing particles emerging from the attitude jet nozzles. He was observing them under especially favorable circumstances, namely at a time when the sun was up but the window faced away both from the sun and from the earth, so that he had a black sky against which to see them. Furthermore, he was dark-adapted. Under these circumstances he could see objects as faint as the fourth magnitude, as compared with an estimated $-9$ magnitude for the objects seen by Glenn (refs. 20 and 21). They must thus have been as much as 100,000 times fainter, corresponding to the difference of 13 magnitudes. Thus, their diameters may have been as small as 25 microns. For such small particles, it is extremely difficult to be sure of the origin. Given the high temperature of the jet exhaust (approximately 1,300° F.), ice crystals would not be expected. Furthermore, most of the material leaving the nozzles should be moving at supersonic velocities if the jets are to be effective in moving mass of the spacecraft. However, Glenn reported seeing a small "V" of steam each time he activated the pitch down thruster (ref. 4). Such steam, under more favorable viewing conditions might appear as individual particles. It appears possible that some of the material in the periphery of the jet exhaust may be moving relatively slowly and cooling rapidly upon leaving the nozzle producing minute droplets or crystals which can be viewed under very favorable conditions. It is possible that these particles are tiny fragments of the catalyst eroded by the hydrogen peroxide blast. In any case, particles coming from the jets were not seen by Glenn, Carpenter, or Schirra, probably because the latter were observing them under less favorable circumstances. Cooper had the enormous advantage that his cabin lights could be completely extinguished and his window covered for extended periods of time to assist him in becoming fully dark-adapted.

### Dim–Light Phenomena

At the time of the beginning of the orbital flight program, it was realized that the most promising field for nighttime observations was the study of extended dim objects, especially immediately after sundown or before sunrise. At all times, the astronaut is above a major portion of the airglow layer; and this means a major reduction in the background illumination. Near the time of twilight, the astronaut has the further advantage over the ground observer that his sky is without twilight except for the band along the horizon. Since the majority of comets are found by ground observers in twilight, the astronauts were urged to keep an eye out for them at this time. It should be noted that a new comet was discovered at the eclipse of July 20, 1963 (ref. 22). It was hoped that the astronaut would observe the no-man's land between the zodiacal light, which can be observed from the ground only at distances of 30° or more from the sun, and the outer corona, which is invisible at distances from the sun more than about 3° (ref. 23). This gap has been partially bridged by airplane flights, but more data are still needed.

Astronaut Cooper reported that at about 20 seconds after sunset, he saw a whitish arch extending some 15° or so out from the sun. Approximately 1 minute after sunset, Cooper successfully observed the zodiacal light as a faint band concentrated along the ecliptic. The failure of previous astronauts to see it was presumably because of lights in the cabin which could not be extinguished. As part of an experiment developed by Ney and his associates

a series of photographs were taken of the zodiacal light, but these were unsuccessful because of the problems described in paper 12.

### Appearance of Earth and Sky at Night

Once the orbital twilight has faded, the visibility of the earth depends upon the phase of the moon. Even with no moon, the earth's horizon is visible to the dark-adapted eye.

According to Cooper, the earth's surface is somewhat darker than the space above it, which is filled not only with the visible stars, but also has a diffuse light produced by the countless stars, which cannot be individually resolved by the eye and by dim light phenomena, such as airglow and zodiacal light. With the aid of starlight, zodiacal light, and airglow, clouds and coastlines are just visible to the dark-adapted eye. With moonlight reflected on the earth, the horizon is still clearly defined, but in this case, the earth is brighter than the background of space. With moonlight, the clouds can be seen rather clearly and their motion is distinct enough to provide a cue to the direction of motion of the spacecraft. Lights from cities can be distinguished, even through thin clouds. Thus the lights of Shanghai shining through the clouds were used by Cooper to help aline his vehicle in yaw on the last night pass prior to retrofire.

The night sky appears quite black with the stars as well defined points of light which do not twinkle. Lights upon the earth do twinkle when viewed from above, according to Cooper.

Comparison of visual estimates of angles near the horizon with the corresponding measurements shows that the so-called "moon illusion" continues to exist in space; that is, objects near the horizon seem to be larger than their true angular dimensions (ref. 21). The fact is interesting, since it shows that this illusion is not related to any sensation of gravity, but is a consequence in some way of the visual perception of the location of the horizon.

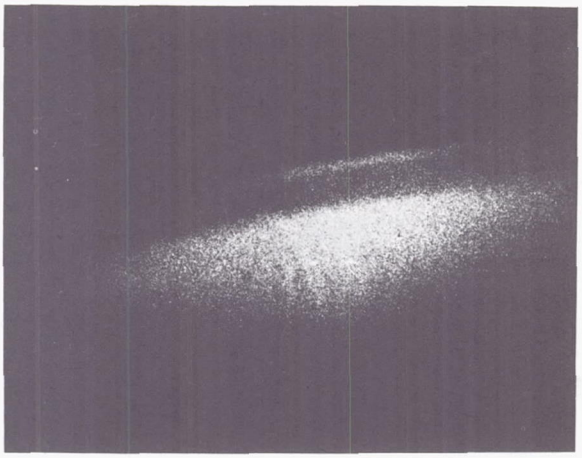
### The Nightglow

Around the horizon, all the astronauts report that they saw a band of light, which appeared to them to be centered at a height of some 6° to 10° above the visible horizon. Astronaut Glenn describes it as "tan to buff"; similar descriptions were given by the others. The nature of the band was made clear by Astronaut Carpenter who employed a filter which passed only the 5577 Å line of the neutral oxygen atom (refs. 21 and 24). Through the filter, the band continued to be visible although all other details of the horizon had vanished. It was thus clear that the band resulted from the phenomenon of nightglow; that is, the emission of light by gases of the high atmosphere. In this emission, the line 5577 plays an important part; it constitutes about ⅙ of the total, according to Tousey and his associates. Carpenter reported that the light seen through the filter seemed to be about the same as that without; this remark should, however, be understood as an indication of order of magnitude rather than as a precise measurement, for which neither time nor instruments were available.

Carpenter also provided a rough estimate of the brightness, indicating that it was comparable with that of a bank of clouds near the horizon illuminated by the quarter moon, or about 30 kilorayleighs, according to later computations. This figure happens to agree closely with rocket measurements (ref. 25).

The height of the nightglow layer was also measured on the MA–7 flight. Carpenter observed the passage of the second magnitude star Gamma Ursae Majoris through the nightglow layer. He timed its entrance into the layer, its passage through the level of maximum brightness, and its emergence. From this information, it has been possible to calculate the height of the nightglow layer, by using the standard formulas for the dip of the horizon. A value of 91 kilometers was found; the close agreement with rocket measurements is probably to be expected, since the method is capable of considerable precision.

On the MA–9 flight, a camera with a f/0.8 lens of 3.8 cm focal length using Ansco H 529 color film was carried to photograph the nightglow (see paper 12). A total of 15 usable exposures were made. Some of these were degraded by roll of the spacecraft during the exposure, but a number of them show the nightglow layer as a thin line a few degrees above the horizon as can be seen in figure 19–13(a). The results of this study are summarized in table 19–II.



(a) Nightglow photograph number 29 (MA–9) (Unretouched).

FIGURE 19–13.—Nightglow photography.

supported by the densitometry of the photographs taken by Astronaut Cooper.

Table 19–II shows the altitudes of the spacecraft as a function of time and the measured angles that the airglow layer has with respect to the observable earth's limb. It also shows the inferred heights of the airglow layer, and these heights vary from somewhat in excess of 100 kilometers down to something just under 80 kilometers. The average height as determined from all the pictures is 88 kilometers, and the thickness of the layer is 24 kilometers. There is an indication (figs. 19–13 (a), (b), and (c)) that the earlier photographs of the airglow layer show it higher above the horizon as determined by lightning flashes on the horizon

*Table 19–II.—MA–9—Nightglow Photographs Used for Geometrical Measurements*

[From Gillett, Huch, and Ney, U. of Minn.]

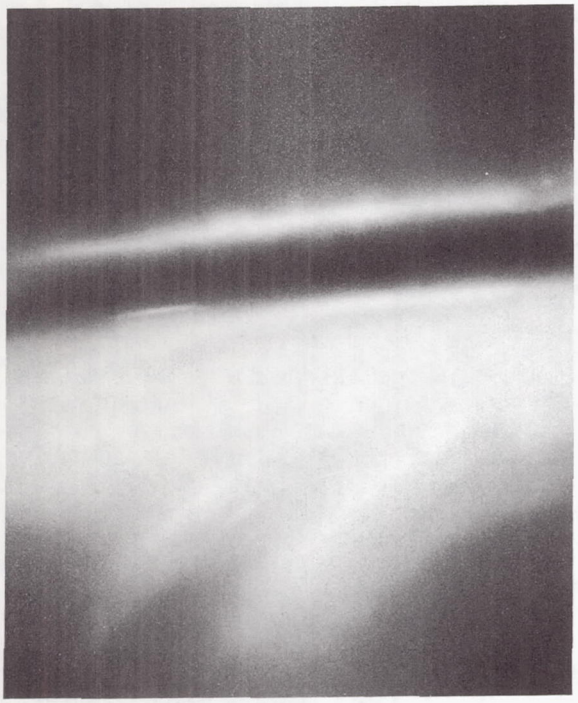
| Picture No. | Time, G.m.t. | Angle between earth's limb and nightglow line, deg | Height of spacecraft above earth, km | Height of center of nightglow band, km | Latitude at which nightglow is observed | Angular width at half intensity of nightglow band, deg | Normal exposure time, sec |
|---|---|---|---|---|---|---|---|
| 22 | 1342:50 | 3. 62 | 241 | 111 | 27° S. | 0. 66 | 30 |
| 23 | 1343:10 | 3. 26 | 240 | 105 | 26.5° S. | . 69 | 10 |
| 25 | 1346:20 | 3. 00 | 232 | 97 | 23° S. | . 88 | 30 |
| 27 | 1349:30 | 2. 26 | 220 | 75 | 18° S. | . 71 | 120 |
| 28 | 1350:20 | 2. 40 | 218 | 78 | 17° S. | . 89 | 30 |
| 29 | 1350:40 | 2. 41 | 217 | 77 | 16.5° S. | . 87 | 10 |
| 31 | 1355:00 | 2. 66 | 202 | 81 | 8° S. | . 78 | 30 |
| 32 | 1355:10 | 2. 65 | 202 | 81 | 8° S. | . 78 | 10 |
| 35 | 1401:40 | 3. 20 | 181 | 87 | 8° N. | . 92 | 10 |
| Average | ---------- | 2. 86 | ---------- | 88 | ---------- | 0. 80 | ---------- |

The color of the nightglow band, as determined from the photographs, is greenish with respect to the bluish-white illumination of the earth. It is not, however, the same green as a pure 5577 Å line since, as noted above, the light of the 5577 Å line is diluted with other radiations.

On some of the photographs, the atmospheric clouds and haze near the horizon can be seen, illuminated by the moon, then at last quarter (fig. 19–13(b)). As remarked by Carpenter (ref. 24), the brightness of the nightglow layer is comparable with that of the clouds illuminated by the quarter moon; this conclusion is than the later pictures, in which the earth's limb is illuminated by the quarter moon. This could be true latitude effect, and, if it were, would indicate that the airglow layer has a higher altitude at high latitudes—the highest latitude in this case being about 27° S. where the layer is about 108 kilometers as measured from the lightning horizon references. The lowest altitude of the airglow layer is near 17° and is about 78 kilometers.

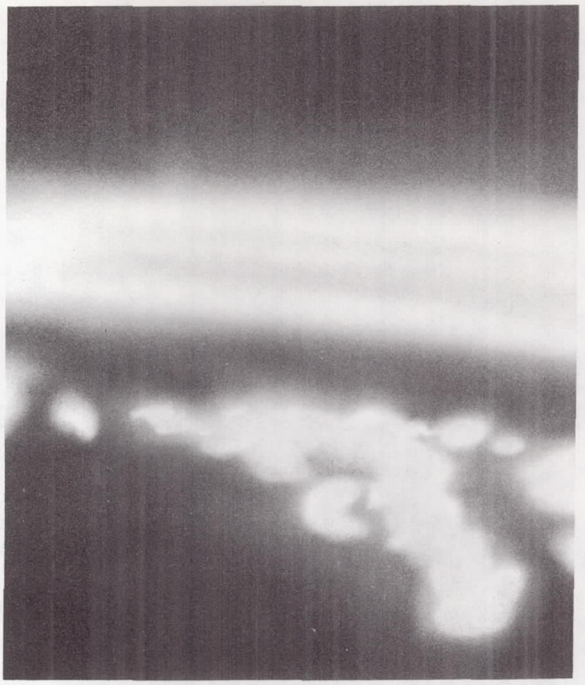
The width of the nightglow band at the half-intensity points was measured from the films as between 0.66° and 0.92°. By comparison, the distance from the center of the nightglow layer to the bottom was measured by Carpenter and his coworkers (ref. 24) as 0.34°; he did

not measure the entry of the star into the layer. Carpenter's half width is in good agreement with the photographed total width; both indicate that the nightglow layer is considerably narrower than the space between itself and the horizon. Table 19–III summarizes and compares the data from the MA–7 and MA–9 flights.



(b) Artist sketch based on nightglow photograph number 29 (MA–9).
FIGURE 19–13.—Continued.

Astronaut Schirra observed on one occasion on the night side, while over the eastern portion of the Indian Ocean and probably while looking in a northerly or northeasterly direction, a large luminous patch which he described as a brownish smog-appearing patch. He saw stars above and below this patch which he felt was higher and thicker (wider) than the "normal" nightglow. On the average, this higher patch or layer did not seem to be as bright as the "normal" nightglow layer. Some stars could be seen near the feathered edges of the layer, but he was not certain he could see any stars in the central denser portion (nor is it likely that, at the short period of observation, there was a rich and bright star field in the background). It is tempting to conclude that this phenomenon may have been a view of a



(c) Artist sketch based on nightglow photograph number 22 (MA–9).
FIGURE 19–13.—Concluded.

tropical 6300 Å atomic oxygen emission, first reported by Barbier and his associates (ref. 14). It is believed that the arc observed by Schirra is similar to that observed at Tamanrasset, Algeria, and Maui, Hawaii. On one occasion, Cooper noticed and immediately reported a patch, similar to that described by Schirra, above the "ordinary" nightglow layer while over South America. It had been predicted that there might be visual concomitants of the South Atlantic magnitude anomaly; however neither of these observations were in the correct geographical location to be related to this phenomenon.

*Acknowledgments.*—In addition to the individuals specifically referred to in the text of this section, the following scientists assisted in the development of the Mercury inflight research program as consultants, or members of the "Ad Hoc Committee on Scientific Experiments," or the "Panel on Inflight Scientific Experiments" of the NASA Office of Space Sciences: Jocelyn R. Gill, Ph. D., NASA Headquarters; Gordon C. Augason, NASA Ames Research Center; Maurice Dubin, NASA Goddard Space Flight Center; Frederick R. Gracely, NASA Headquarters; John E. Naugle,

*Table 19–III.—Comparison of MA–7 and MA–9 Nightglow Observations*

| Type of measurement | Carpenter et al. | Cooper photographs |
|---|---|---|
| Color | At least partly 5577 | Whitish green. |
| Brightness | Like a cloudbank under a quarter moon; 30 kilorayleighs. | Same. |
| Height | 91 km | 88 km. |
| Width | 0.68° | 0.66° to 0.89° |

Ph. D., NASA Headquarters; Freeman H. Quimby, Ph. D., NASA Headquarters; George P. Tennyson, NASA Headquarters; Ernest J. Ott, NASA Headquarters; Albert Boggess, III, Ph. D., NASA Goddard Space Flight Center; George Swenson, Ph. D., U. of Illinois; Franklin Roach, National Bureau of Standards; Edward P. Ney, Ph. D., U. of Minnesota; Leslie Meredith, Ph. D., NASA Goddard Space Flight Center; and Dale W. Jenkins, Ph. D., NASA Headquarters.

## References

1. Minnaert, N.: *The Nature of Light and Color in the Open Air.* Dover Publications, Inc. (New York), 1954.
2. Shepard, Alan B., Jr.: *Pilot's Flight Report, Including In-Flight Films.* Proc. Conf. on Results of the First U.S. Manned Suborbital Space Flight. NASA, Nat. Inst. Health, Nat. Acad. Sci., June 6, 1961, pp. 69–75.
3. Grissom, Virgil I.: *Pilot's Flight Report.* Results of the Second U.S. Manned Suborbital Space Flight, July 21, 1961. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 47–58.
4. Glenn, John H., Jr.: *Pilot's Flight Report.* Results of the First U.S. Manned Orbital Space Flight, February 20, 1962. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 119–136.
5. Strombros, W.: *Letter to the Editor,* Aviation Week, August 12, 1963, p. 118.
6. Middleton, W. E. K.: *Vision Through the Atmosphere.* University of Toronto Press, 1952, pp. 122 ff.
7. Blackwell, H. R.: *Contrast Thresholds of the Human Eye.* J. Optical Soc. of America, vol. 36, 1946, pp. 624–643.
8. Zoethout, W. D.: *Physiological Optics.* The Professional Press, Inc., 1947, pp. 247–353.
9. Baumann, R. C., and Winkler, L.: *Photography From the Viking II Rocket at Altitudes Ranging up to 158 Miles.* Naval Research Lab. Rep. 4489, 1955.
10. Lowman, Paul D., Jr.: *Photography of the Earth From Sounding Rockets and Satellites.* Photogrammetric Engineering Journal. (In press.)
11. Rod, E.: *Faul Pattern, Northwest Corner of Sahara Shield.* Bull. Am. Assoc. Petroleum Geologists, vol. 46, No. 4, 1962, pp. 529–552.
12. Soules, S. D,. and Nagler, K. M.: *Weather Observations From Manned Space Stations.* Paper presented at the XIV International Astronautical Congress of the International Astronautical Federation in Paris, France, September 25 to October 1, 1963.
13. Schirra, Walter M., Jr.: *Pilot's Flight Report.* Results of the Third United States Manned Orbital Space Flight, October 3, 1962. NASA SP–12. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 49–55.
14. Barbier, Daniel, and Glaume, Jeanine: *Les Radiation de L'oxygène 6300 et 5577Å de la Luminescence du Ciel Nocturne dans Une Station de Basse Latitude.* Annales de Geophysiqué, vol. 16, Issue No. 3, 1960, pp. 319–334.
15. Alexander, E. N., McCracken, C. W., et al.: *Review of Direct Measurements of Interplanetary Dust From Satellites and Probes.* Space Research III. Proc. of 3d International Space Sciences Symposium, Washington, May 1962. North Holland Publishing Co. (Amsterdam).
16. Carpenter, M. Scott: *Pilot's Flight Report.* Results of the Second United States Manned Orbital Space Flight, May 24, 1962. NASA SP–6. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 69–75.
17. Cameron, W. Sawtelle, Glenn, J. H., Carpenter, M. S., and O'Keefe, J. A.: *The Effect of Refraction on the Setting Sun as Seen From Space in Theory and Observation.* Astronautical Journal, vol. 68, no. 5 1963, pp. 348–351.
18. Volz, S. E., and Goody, R. M.: *The Intensity of the Twilight and Upper Atmospheric Dust.* J. Atmospheric Sciences, vol. 19, no. 5, 1962, pp. 385–406.

19. DUNKELMAN, L.: *Visual Observations of the Atmosphere From U.S. Manned Spacecraft in 1962.* Paper presented to the IV International Space Sciences Symposium of COSPAR, Warsaw, Poland, June 6, 1963.
20. GLENN, JOHN H.: *The Mercury-Atlas 6 Space Flight.* Science, vol. 136, June 1962, pp. 1093–1095.
21. O'KEEFE, JOHN A., and CAMERON, WINIFRED SAWTELL: *Space Science Report.* Results of the Second United States Manned Orbital Space Flight, May 24, 1962. NASA SP–6. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 35–42.
22. DOSSIN, F. D.: *Goddard News*, vol. 5, no. 7, September 9, 1963, p. 1.
23. ROACH, F. E., and VAN BIESBROECK, G.: *The Zodiacal Light and Solar Corona.* Sky and Telescope, vol. 13, no. 5, March 1954.
24. CARPENTER, M. S., O'KEEFE, J. A., and DUNKELMAN, L.: *Visual Observations of Nightglow From Manned Spacecraft.* Science, vol. 138, 1962, pp. 978–980.
25. KOOMEN, M. J., GULLEDGE, I. S., PACKER, D. M., and TOUSEY, R.: *Night Airglow From Orbiting Spacecraft Compared With Measurements From Rocket Observations.* Science, vol. 140, 1963, p. 1087.

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# 20. ASTRONAUT'S SUMMARY FLIGHT REPORT

By L. Gordon Cooper, Jr., *Astronaut, NASA Manned Spacecraft Center*

**Summary**

The MA–9 flight marked the conclusion to the United States' first manned space-flight program. From their initiation into the program in 1959, the seven Mercury astronauts participated as a specialist team, and their combined experiences, both in space and on the ground, constitute a valuable contribution to the nation's manned space-flight capability. The launch checkout activities constitute one of the most valuable portions of this experience, and the MA–9 flight demonstrated once again how critical this period is both to the preparation of the spacecraft and the pilot. The sensations and experiences of the flight were generally similar to those reported by the pilots of previous flights with the exception that better dark adaptation was obtained and therefore more dim light phenomena could be seen. During the MA–9 flight, the zodiacal light and what may have been the daytime airglow were observed for the first time. While some new observations were made on phenomena such as the airglow and space particles, the appearance of the earth features and weather patterns generally seemed to be similar to the description of the previous pilots. As on previous flights, several photographic studies were conducted and the results of these exercises have proved to be valuable. A series of new experiments and evaluations of Mercury systems were conducted, with generally good results. The mission appeared to be relatively routine until a malfunction in the control system late in the flight made it necessary to control attitude manually during retrofire and reentry. The flight of *Faith 7* concluded after some 34 hours in space with a landing within 4½ miles of the primary recovery ship, the *USS Kearsarge*, in the Pacific Ocean.

**Introduction**

When the seven of us came together as a group for the first time at Langley Field, Virginia, in April of 1959, neither we, any of the newly created NASA Space Task Group, nor anyone in the country knew what our exact roles as Project Mercury Astronauts would entail. We were unsure how we should train for space flights, how we would become familiar with the spacecraft and its many systems, or even how the pilot would be integrated into these systems. We were all starting from scratch, from the ground floor in manned space flight.

Looking back now on more than 4 years of concentrated training, detailed study of spacecraft systems, attending countless hundreds of coordination and planning meetings, participating in hundreds of hours of hardware development and checkout, we can all recognize that in some cases there would have been more efficient ways of doing things. However, considering the limited knowledge in this space business in the spring of 1959, I consider it remarkable that Project Mercury ran so close to its originally planned time schedule. Few programs in the history of airplane development ever ran as close, and no airplane program ever had so many unknowns staring the test operations team in the face.

By correlating all that we have learned in the last 4 years and properly applying it to future manned space programs, we should be able to increase the efficiency of our next program. This application of experience will be important because taking the step from the successful missions of Project Mercury to manned interplanetary flights involves many stumbling blocks and unknowns. These uncertainties must be uncovered and solved in a logical manner.

Back in 1959, the pilot was one of the real unknowns in space flight. No one could really say for certain how a pilot would react or how

well he could perform in a space environment. Partially for this reason and because unmanned flights were scheduled as part of the development program, the Mercury spacecraft was designed to perform the mission automatically. Manual controls for spacecraft control and systems management were included primarily as backups to the automatic program. From the start of the program we encouraged the concept of the pilot being a primary part of the overall system. Throughout the manned flight phase, this concept has become more and more of a reality.

While we adopted the team concept during most of our space-flight training, we were required to be at so many places and cover so many areas that each man was assigned a specialty area to monitor closely and brief the others on periodically.

"Faith 7" was the name I selected for the spacecraft which performed so well for me until the electrical problem late in flight. I chose this name as being symbolic of my firm belief in the entire Mercury team, in the spacecraft which had performed so well before, and in God. The "7," of course, as in the names used by the others before me is representative of the original astronaut team. This flight report will present a discussion of my entire flight experience, but I shall attempt to summarize the in-flight sensations and observations of the other astronauts and relate their experiences to my own. Beginning with the prelaunch activities which are so necessary to preparing for the mission and concluding with my landing in the Pacific after 34 hours of weightlessness, I shall try to discuss the many experiments and systems operation in which each of us took part.



FIGURE 20–1.—Astronauts Cooper and Shepard discuss MA–9 camera during prelaunch activities.

## Preflight And Launch

### Spacecraft Readiness and Checkout

The period from the time the spacecraft arrived at Cape Canaveral until the time it was mated with the launch vehicle was the period where the pilot and his backup became completely familiar with the spacecraft and all its various systems (fig. 20–1). We learned all the individual idiosyncrasies of each system. We also became familiar with many of the members of the launch crew and learned whom to call on for expert advice on each system. It was also during this period that we had an opportunity to discuss the coming flight with team members who had flown before (fig. 20–2) and take advantage of their experiences.

The preflight phase was used to incorporate certain modifications into the spacecraft and

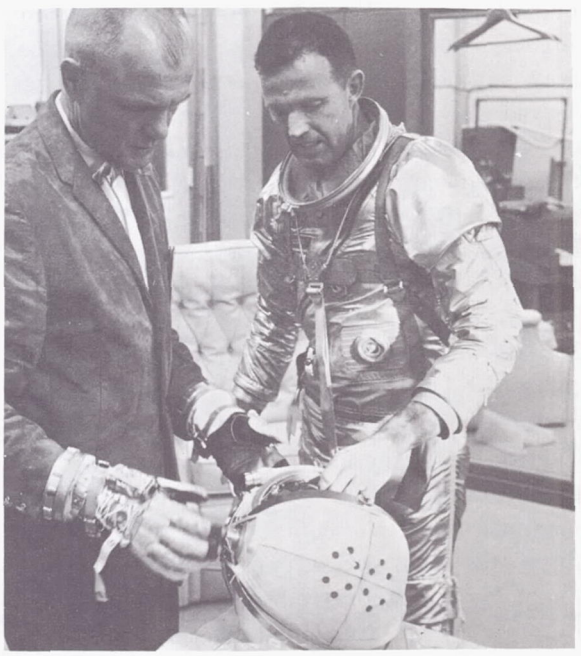


FIGURE 20–2.—Astronauts Glenn and Cooper discuss items of the pilot's personal equipment during the MA–9 prelaunch period.

to add some pieces of equipment necessary to meet operational requirements. Because of the limited usable cockpit space and the even more limited center-of-gravity travel and gross weight of the Mercury spacecraft, these configuration changes were always a soul-searching problem. Regardless of how they were accomplished, additions often resulted in some type of compromise to the pilot's comfort, freedom of movement, and/or operational smoothness.

The natural tendency was for everyone to want to improve on existing equipment and to add worthwhile experiments that could be fitted in. Space flight is so expensive that no one wants to waste a single second of orbital time. However, we all discovered that the entire flight is compromised when all equipment, all experiments, and all the flight plan detail are not frozen early enough to check out each piece of equipment and allow everyone, particularly the pilot, to become thoroughly familiar with all procedures.

On all our flights the cockpits have been cluttered to the point where the space remaining for the astronaut and the equipment with which he must work is very limited and inefficiently arranged. In most cases getting some of the equipment located and moved about provided more exercise than did the special onboard exercise device. Stowage of equipment is a very real problem that too often is not given enough consideration.

As the flights lengthened, a detailed flight plan and abbreviated checklists for experiments and operational procedures became a real necessity. It is impossible for a pilot to remember all the details of times, amounts, and so forth, of the many experiments and tests to be conducted. Proper formats and storage for these items had to be developed during the preflight preparation periods.

#### Integrated Checkout

*Faith 7* passed all the spacecraft tests in fine shape and was taken to the launch complex to be mated with the Atlas 130D launch vehicle. At this time, a buildup of integrated launch vehicle and spacecraft tests, system by system, was initiated and proceeded until the program was culminated in a fully integrated simulated flight from countdown to recovery with all systems operating. This series of tests was felt by all of us to be a necessity not only to check out all the systems, but to train the launch crew, the pilots, and the personnel of the worldwide network.

#### Countdown

I believe that we can very readily shorten the time that the pilot is in the spacecraft prior to launch. I was busy enough with the countdown activities that time did not drag, but I did have time to take a short nap during this period. It seems to me that to conserve the pilot's energy it would be desirable to accomplish more of these checks with the backup pilot prior to insertion. Of course, you do need a few minutes to shift around and get settled, see that the equipment is located properly, before you are prepared for the flight.

Most of the countdowns in Mercury went fairly smoothly as a result of the practice that the launch crews had acquired on simulated flight tests. The first attempt to launch MA–9 on May 14 was delayed for a diesel engine that would not operate to drive the gantry back. Then it had to be postponed because a critical radar set became inoperative. I was in the cockpit for some 6 hours before we scrubbed on that first day. I was quite tired but felt ready to recycle for another count the following day.

The countdown on May 15, 1963, went almost perfectly. Everything was really in a "go" status and I think everyone felt that we were going to have a good launch. And it was!

I had thought that I would become a bit more tense as the count neared minus 1 or 2 minutes, but found that I have been more tense for the kick-off when playing football than I was for the launch on May 15. I felt that I was very well trained and was ready to fly a good flight.

### Powered Flight

It is a wonderful feeling when the engines light and you have lifted off. The long period of preparation is over, and at last you are ready to settle down to your work.

The acceleration is not disconcerting or degrading at the levels encountered in the Mercury flights. In fact, it gives one somewhat the same feeling as that of adding full throttle on a fast car, or a racing boat, or a fighter airplane. The pilot can easily monitor several of the more

critical parameters, including his attitudes, throughout the entire launch phase. The task that he is given to do should be uncluttered with minor details if possible, but he is fully capable of functioning as an intricate part of the system throughout the entire launch. I was surprised at how many things I could keep track of and feel that I had plenty of time to do the exact item planned.

On previous flights, it had been noted that vibration encountered in the region of maximum dynamic pressure was feeding through the couch to the helmet and causing slight blurring of vision. We found that this could be eliminated by adequate padding between the helmet and the couch. I had approximately ¾ inch of foam rubber between my helmet and the couch and experienced no blurring of vision.

Booster engine cutoff (BECO) is very distinctive, by the decrease in both the acceleration and the noise. It was just as I had expected it to be from talking to the others.

John Glenn and Scott Carpenter had discussed with Wally Schirra and me how they had encountered some springboard effect from the guidance while in the latter phases of the sustainer flight. Wally Schirra experienced very little or none of this effect. I had an almost perfect sustainer trajectory with almost no guidance corrections at all, so it was an exceptionally smooth and almost perfect insertion.

Sustainer engine cutoff (SECO) is also quite distinctive, in the same manner as BECO. This is followed by the noise of clamp rings and posigrade rockets. The spacecraft is in orbit.

## Orbital Flight

### Insertion

We had all run many full launch profiles on the centrifuge, so I felt very well prepared for all the powered flight, but there is some difference between the transition from positive acceleration on a centrifuge back to 1–g and the transition from positive acceleration on the flight to zero–g. I felt somewhat strange for the first few minutes. The view out of the window is a tremendous distraction as the spacecraft yaws around and the earth and the booster come into full view for the first time. We all noted a strong desire to concentrate on the tremendous view out of the window. Atlas 130D was only about 200 yards away from me. It was certainly beautiful. I could read the lettering on the sides and could see various details of the sustainer. It was a very bright silver in color, with a frosty white band around the center portion of it. It was still wisping vapor from the aft end. It was yawed approximately 15° to 20° to its left. I had it in sight for a total of approximately 8 minutes. The front end was slowly turning in counterclockwise rotation.

Despite these distractions, the many hours of training took over and we all proceeded to do our tasks as scheduled. After a few minutes I readily adapted to the new environment and felt completely at ease. Weightlessness is extremely comfortable. After a pilot has once experienced weightlessness in space flight, he should almost immediately adapt to this condition when exposed to it again. We all even tended to forget we were weightless.

I agree with Scott Carpenter that the cockpit did seem to be somewhat differently located in respect to myself upon insertion into orbit. You move up forward in the seat, regardless of how tight your straps are cinched. The equipment storage kit on the right seems to be at a different angle to you than it is when you are on the launch pad. I did feel very distinctly that I was sitting upright. Most of the time I felt as if I were lightly floating. A couple of times I felt almost as if I were hanging upside down because of the feeling of floating into the shoulder straps. Because the spacecraft was weightless, equipment stayed where it was whenever I let go of it. Nevertheless, every time I "dropped" something, I had the tendency to grab below it, expecting it to fall.

You really need to have a low workload on the first pass in order to collect your senses, to acclimatize yourself to this new situation, and to organize the flight activities. I felt that I was not on top of the situation as completely as I would like to be right after insertion. Although I was thinking about all the items to be done and of how to do them, I did not feel completely at home. I felt that I was in a strange environment and was not at my best, until perhaps halfway through the pass. By the end of the first pass, I was feeling really adjusted to my new surroundings.

One indication of my adjustment to the surroundings was that I encountered no difficulty

in being able to sleep. When you are completely powered down and drifting, it is a relaxed, calm, floating feeling. In fact, you have difficulty not sleeping. I found that I was catnapping and dozing off frequently. Sleep seems to be very sound. I woke up one time from about an hour's nap with no idea where I was and it took me several seconds to orient myself to where I was and what I was doing. I noticed this again after one other fairly long period of sleep. You sleep completely relaxed and very, very soundly to the point that you have trouble regrouping yourself for a second or two when you come out of it. However, I noted that I was always able to awaken prior to having a task to do. I did not encounter any type of the so-called "break-off phenomena." Although this flight was very enjoyable, a thing of delight, it still is a strange environment to a human being and you have every desire to get back to earth at the planned time.

#### Comments on Systems Operation

The automatic control is rather sloppy due to the wide limit cycle it operates within. It is no problem as soon as you get accustomed to it. I found that Grissom's and Schirra's description of the manual proportional flight control system was very accurate. It is a rather sluggish system until you learn to use short blips. The fly-by-wire low is much more precise with the crispness of control produced by the firing of the 1-pound thrusters.

I found that orienting the spacecraft after drifting flight was quite easy on the day side and not too difficult on the night side, although orientation on the night side takes more time unless there is moonlight or broken clouds or land masses below. Stars and star patterns are more difficult to recognize because of the limited view through the window. You can slowly drift until you find a star pattern that is recognizable and from this you can pick up a zero yaw star. If you have moonlight, or any broken cloud masses or land masses, you can pick up zero yaw very readily if you turn all the lights off in order to become dark adapted and pitch down to approximately $-20°$.

Speed is very apparent when flying over clear or broken-cloud areas. However, if there is a solid cloud deck underneath you and no other motion cues are available, you have a very slow, floating feeling.

When I was drifting, the changing view out the window was not at all disconcerting, and the random orientation caused me no concern. In fact, it is a very relaxed way to travel. I might mention an item here on the natural dynamics of the spacecraft. When rates were near zero, and the spacecraft was powered down, I never observed any rate greater than 1°/sec about any one axis. Generally, if there were a rate about one axis as great as this, there were no rates about the other two axes. These rates would switch from axis to axis and more than likely only two axes would have any rate at all, and these rates would be between $\frac{1}{4}$°/sec and $\frac{1}{2}$°/sec, at the most. Frequently, for long periods of time, the spacecraft would have absolutely no rates at all and would be almost completely motionless. The one axis that appeared to have more predominate rates than the others was the roll axis; and the rate, almost invariably, was to the left, approximately $\frac{1}{2}$°/sec.

Although my suit temperature was satisfactory, like Wally Schirra I had to adjust the water flow continually to attempt to hold temperature in limit. The condensate pump that was added just prior to launch failed; so that the condensate tank filled up and the suit was very moist all the time.

The valve on the drinking water container was leaky, and I was unable to place water into the plastic freeze-dehydrated food containers. Therefore, I ate only the bite size foods.

#### Visual Sightings

During the day, the earth has a predominately bluish cast. I found that green showed up very little. Water looked very blue, and heavy forest areas looked blue-green. The only really distinctive green showed up in the high Tibetan area. Some of the high lakes were a bright emerald green and looked like those found in a copper-sulphate mining area. The browns of the Arabian desert showed up quite distinctly, but the Sahara was not quite so brown. If you are looking straight down on things, the color is truer than if you are looking at an angle.

I could detect individual houses and streets in the low-humidity and cloudless areas such as the Himalaya mountain area, the Tibetan plain, and the southwestern desert area of the U.S. I saw several individual houses with smoke coming from the chimneys in the high country around the Himalayas. The wind was apparently quite brisk and out of the south. I could see fields, roads, streams, lakes. I saw what I took to be a vehicle along a road in the Himalaya area and in the Arizona-West Texas area. I could first see the dust blowing off the road, then could see the road clearly, and when the light was right, an object that was probably a vehicle.

I saw a steam locomotive by seeing the smoke first; then I noted the object moving along what was apparently a track. This was in northern India. I also saw the wake of a boat in a large river in the Burma-India area.

At times during the day, the pattern of the sun coming through the window was hot on my suit. I could also feel heat on the inside of the window right through my glove. Like Scott, I never tired of looking at the sunsets. As the sun begins to get down towards the horizon, it is very well defined, quite difficult to look at, and not diffused as when you look at it through the atmosphere. It is a very bright white; almost the bluish white color of an arc lamp. As it begins to impinge on the horizon line, it undergoes a spreading, or flattening effect. The sky begins to get quite dark and gives the impression of deep blackness. This light spreading out from the sun is a bright orange color which moves out under a narrow band of bright blue that is always visible throughout the daylight period. As the sun sets farther, it is replaced by a bright gold-orange band which extends out for some distance on either side, defining the horizon even more clearly. The sun goes below the horizon rapidly, and the orange band still persists but gets considerably fainter as the black sky bounded by dark blue bands follows it on down. You do see a glow after the sun has set, although it is not ray-like. I could still tell exactly where the sun had set a number of seconds afterward.

At night I could see lightning. Sometimes five or six different cumulus buildups were visible at once. I could not see the lightning directly, but the whole cumulus mass of clouds would light up. From space, ground lights twinkle, whereas stars do not. I could not distinguish features on the moon. It was a partial moon at night, but it appeared full when it was setting in the daytime. It was quite bright at night, but on the day side it was a lightish blue color.

I immediately saw the airglow layer, which all the orbital pilots have seen, in which the stars appear to fade as they pass through it and then reappear below it before disappearing behind the horizon. The earth has a sharp horizon even at night. At the time, the layer appeared to be about 12° to 13° high. It was, of course, actually lower than this as discussed in paper 19.

At two different times, I saw a faint glow just after sunset or prior to sunrise; it was somewhat cone shaped, and I believe it was the faint glow of zodiacal light. It was not exactly perpendicular to the horizon. I had a feeling that this was just a glow off the sun. It was not as bright as the Milky Way. Another night phenomenon that I noticed occurred when I was over South America looking east or northeast. It appeared to be the lower edge of a cloud ceiling on an overcast day. It did not appear to have an upper edge. It was not distinct and did not last long, but it was higher than I was, was not well defined, and was not in the vicinity of the horizon. It was a good sized area, very indistinct in shape. It had a faint glow with a reddish brown cast. It seemed to be quite extensive, very faint, and contrasted as a lighter area in the night sky. It may have been the same high airglow layer that Wally reported.

When there is no moon, the earth is darker than the sky; there is a difference in the two blacks. In general, there was more light from the sky; the sky is a shining black as compared with a dull black appearance of the earth. There is a distinct line at the horizon and the earth is the darker.

I saw the lights of Perth, Australia, and a bright orange light from the British oil refinery to the south of the city. If there is moonlight, then cloud layers and ground features can be seen. The moonlight was bright enough to detect motion of the ground. On several occasions I could see light from cities on the ground through the clouds. On the last night pass, I

used the light of Shanghai glowing through the clouds to help me line up in yaw for retrofire.

At times I could see the glow from every one of the thrusters. I saw a tremendous amount of John Glenn's fireflies regardless of my attitude. They appeared to come out from the spacecraft and go back along the flight path. I could see some of them for as long as 30 or 40 seconds. I could see them coming directly out of the pitchdown thruster when it was activated. I had the feeling that the direction of their motion back along the orbital path was distinct enough that they could be used as a rough yaw reference.

The first indication I got of the sun coming up behind me was the lighting of the clouds from underneath. I noted the clouds getting lighter and lighter, and I could still see the stars. Suddenly, my window would get into the oblique sunlight and appear to frost over just as an aircraft canopy does. This was the result of a greasy coating on the inside of the outer pane, which completely occluded my vision under these lighting conditions.

#### Experiments

Since MA–9 was so much longer than previous flights, I had ample time to conduct numerous experiments. The first orbital flight had very few experiments. As the experimental program increased and the flights lengthened, the number of experiments carried on board increased. In addition to the experiments all of us have tried to make as careful observations as possible. We have been told that these observations of new phenomena can provide some of the most valuable data on features such as the spectacular colors in sunrises and sunsets, zodiacal light, airglow, space particles, stars on the day side, and various distinct earth features (see paper 19).

*Photography.*—All the orbital flight pilots have carried along a hand-held camera of some type for color photographs of interesting phenomena. These have all yielded some good photos of the earth from a new vantage point.

Several photographic programs were carried out during the orbital flight program. Scott Carpenter took horizon definition pictures for MIT, and Wally Schirra made an evaluation of several different filters for the Weather Bureau. These two studies were extended on my flight. In addition, I attempted to get dim light photographs as well as movies (see paper 12).

*Ground light experiment.*—The ground light experiment was attempted on all the orbital flights. However, weather precluded John, Scott, and Wally from seeing it. I was fortunate enough to have excellent weather and saw the ground light as scheduled. The lights from the town of Bloemfontein, S. Africa, were more distinctive than the signal light and helped me to locate it.

*Flashing light experiment.*—On the MA–9 flight, we tried a new experiment designed to provide information that would help us on future rendezvous missions. A 5.75-inch-diameter sphere with two xenon-gas discharge lamps which strobed at approximately one flash per second was ejected from the spacecraft into its own orbit. In this orbit, it moved back and forth relative to the spacecraft so that it would appear at different distances.

At 3:25:00 I went to fly-by-wire low, slowly pitched up to the −20° mark on the window, deployed the flashing beacon, and there was a loud "cloomp" as the squib fired and it departed. I then caged the gyros and powered down the ASCS a-c bus. I never did see the beacon on that first night after it was ejected. However, I was having some difficulty finding my 180° yaw and the spacecraft may not have been properly alined for making the observation. I tried unsuccessfully to observe the flashing beacon early on the day side also.

On the second night side after deploying the flashing beacon, shortly after going into the night side, I spotted the little rascal. It was quite visible and appeared to be only 8 to 10 miles away. I deliberately moved off target, waited until 5:40:00 and eased back to 180° yaw and saw the light again, at which time it appeared to be around 12 to 14 miles away and still quite visible.

On the third night side after deploying the flashing light, I had no anticipation of seeing it at all; but at 6:56:00 ground elapsed time (g.e.t.) there it was, blinking away. It was very faint and appeared to be at a distance of about 16 to 17 miles. I would say it was approximately the brightness of a fifth-magnitude star, whereas on the second night side after deployment it had appeared to be about that of a second-magnitude star.

### Systems Difficulties Encountered Towards the End of the Flight

Partial pressure of oxygen in the cabin slowly dropped throughout the flight to about 3.5 psia. I was worried that the network might get concerned about this on the next to the last pass. Also, the partial pressure of $CO_2$ in the suit circuit had gradually increased to a reading of 3.5 mm Hg. I suspected the gage and went to emergency rate flow and did not get any apparent decrease in this reading. However, I did not stay on emergency rate flow very long. I recognized that my breathing was more rapid and deep. The $PCO_2$ gage indicated that we were up over 5 on the gage setting just prior to retrofire. However, I could have gone on emergency $O_2$ flow and accepted slightly higher suit temperatures because of the fans shutting down, which reduces suit circuit flow.

On the 19th orbital pass, I had been switching the warning light control switch to the "off" position in order to darken completely the interior of the spacecraft and thus become dark adapted. When I returned the switch from the "off" to "dim" position, the 0.05g green light illuminated. I immediately turned off the ASCS 0.05g switch fuse and the emergency 0.05g fuse. Thereafter, we made three checks to verify that the ASCS 0.05g relay functions were operative. Since the amp-cal was now latched into the reentry mode, the attitude gyros were no longer operational.

The 250 v-amp main inverter failed to operate on the 21st pass. At about 33 : 03 : 00 g.e.t. the automatic changover light for the standby inverter came on. I had noticed two small fluctuations in the ammeter just previous to this time and had gone through an electrical check; everything appeared normal. The temperature on the 250 v-amp inverter was about 115° F. The temperature on the fans inverter was about 125° F, and the standby inverter was about 95° F. At this point the light came on and I checked the inverters. The 250 v-amp inverter was still reading about 115° F on temperature, but it was indicating 140 volts on the ASCS a-c bus voltage. I then turned it off. At that time I selected the slug position (manual selection of the standby inverter for the ASCS) and found that the standby inverter would not start. I put the switch back to the "off" position of ASCS a-c power and elected to make a purely manual, or fly-by-wire, retrofire and reentry.

Analysis of these malfunctions illustrated that the entire Mercury network had developed an operational concept of teamwork that culminated in an almost perfect example of cooperation between the ground and the spacecraft on the MA–9 flight. Almost everyone followed the prestated ground rules exactly, and the radio discipline was excellent.

### Retrofire

All of us believed that we could control attitude manually during retrofire. However, the flight plans call for autopilot control. Nevertheless, because of failures of one type or another, Wally's was the only flight in which only the autopilot controlled attitude during retrofire. John had trouble with a low-torque thruster and elected to assist the autopilot with the manual proportional system. Scott had a problem with the horizon scanner and controlled during retrofire with the fly-by-wire and manual proportional systems. I had a malfunction associated with one of the control relays which eliminated my autopilot as well as my attitude indicators. Therefore I had to initiate retrofire, use window view for attitude reference, and control the spacecraft with the manual proportional system. This was no problem, though I did have some difficulty reading the rate indicators due to the large variation in illumination between the inside and outside of the spacecraft. This disparity in illumination became a problem because I had to shift back and forth for attitude reference outside and readings of the rate indicators inside. In order to be ready for retrofire which had to occur just after first light, I oriented the spacecraft to the retrofire attitude on the night side. Night orientation is no problem, but it does take considerably longer, because yaw determination is more difficult than on the day side.

As with the others, there was no doubt in my mind when the retrorockets fired. They produce a good solid thump which you can see and hear. However, our sensations at the time they fired were different. John Glenn felt like he had reversed direction and was going "back toward Hawaii." Scott Carpenter felt that he came to a standstill. Wally Schirra and I did not feel that the motion of the spacecraft changed.

### Reentry

After retrofire, there is a period of several minutes prior to the start of reentry (0.05g). As you approach 0.05g, the spacecraft control becomes sluggish and feels as though it wants to start reentry.

As in the retrofire case, all of us knew that we could reenter on manual control. However, the flight plans generally called for autopilot control during reentry. Nevertheless anomalies of system function resulted in partial manual control in all but Wally's flight. I used manual proportional control on MA–9 since I had lost the ASCS and standby inverters during the 20th orbital pass. The reentry worked out very successfully and showed again that the pilot can accomplish this control task very adequately.

I found that the oscillations of the spacecraft were not difficult to damp until I descended to an altitude of approximately 95,000 feet. At this point, the amplitude of spacecraft motions increased as they normally do and it took a substantial increase of control inputs to keep within comfortable limits. The oscillation became more severe at approximately 50,000 feet, but I deployed the drogue parachute at 42,000 feet, as planned, and the spacecraft was quickly stabilized.

The g-forces are more sustained on reentry than on launch but are still easily tolerable.

During reentry there was no uncomfortable increase in cabin temperature. If the pilot is performing a manual reentry, he will be perspiring profusely when landing, but mostly because of the work load rather than the increased temperature.

### Landing And Recovery

Landing at a rate of 30 fps with the landing bag down is a good solid jolt, but certainly tolerable. In fact, one does not really have to be in an ideal position and braced tightly to be able to take this momentary shock in good shape.

There have been varied opinions among the pilots of all the Mercury space flights as to the sensations encountered upon landing in water. When the spacecraft rolls over and goes under the water, there is a natural tendency to wonder if it will sink or float and whether it will right itself. One item we stressed in training was that of preparing during the descent on the parachute to evacuate the spacecraft immediately after landing in the event it starts to sink. If the pilot knows that the recovery forces are in the immediate area, this first period on the water is considerably more relaxed and enjoyable.

By the time the landing occurs, the pilot is perspiring profusely. The air from the snorkels is quite cooling, but the cabin is fairly warm and humid.



FIGURE 20–3.—Astronaut Cooper climbs out of *Faith 7* after the 34 hour MA–9 flight.



FIGURE 20–4.—Astronaut Cooper stands on the deck of the *USS Kearsarge* immediately after egressing from *Faith 7*.

Almost the full gamut of recovery procedures were used in the course of the Mercury program. The recovery procedure is greatly simpified if the spacecraft lands near a recovery ship. In this case, the spacecraft can be lifted out of the water directly onto the deck. However, all the procedures would be simplified even more if land landings were made.

When I first stepped from the spacecraft on board the *USS Kearsarge* I felt fine (figs. 20–3 and 20–4). As I stood still waiting on a blood pressure check, I began to feel dizzy. I mentioned this to the doctors, who then started moving me along. As soon as I took two or three steps, I immediately began to feel clear-headed once more, and at no time did I become dizzy again.

### Concluding Remarks

After my recovery in the Pacific, the aeromedical specialists conducted their prescribed tests designed to glean as much from my flight as possible. Upon my return to the launch site, a series of formal debriefings covering every aspect of my space flight experience were begun. In these debriefings, I found it useful to refer to my previous training, and that of my six colleagues, in describing my sensations and observations. In the 4 years since we were first initiated into Project Mercury, a great deal has been accomplished and a great deal has been learned. Many of the anxieties and misgivings of space flight have been relieved. Although relatively brief, our early training was intensive and complete, and its effectiveness has been proven, we believe, by our ability to participate actively in the operation of the spacecraft. Al Shepard's flight was our first manned launch, and this initial experience in getting the spacecraft, launch vehicle, and the man ready at the same time was valuable. As a result of losing Gus Grissom's spacecraft, our landing and recovery procedures were promptly changed. In John Glenn's flight, a serious control system malfunction and a somewhat frightening but erroneous signal that the heat shield had been released caused some concern among us on the ground, but John's manual retrofire and reentry completed his mission successfully. Scott had a problem in the control system also, but his manual retrofire, although not quite as precise as he would have liked, brought the *Aurora 7* spacecraft home. Wally Schirra, after bringing his suit temperature under control, completed a "textbook" six-pass mission and landed just under 5 miles from the *USS Kearsarge*.

As I think back over my mission, which actually began right after Wally's flight, it has been an exciting experience indeed. The specific training for my 1-day mission, the many engineering reviews of the changes required for the *Faith 7* spacecraft, the physical conditioning, and even the low-residue diet were all memorable parts of the prelaunch preparation. The initial experience of prolonged weightlessness and the magnificent view of the earth takes a while to get used to just as it did for all the orbital pilots, but once I was accustomed to the new surroundings, events and activities proceeded as scheduled. In fact, until that infamous moment in the 19th orbital pass, it seemed like another Wally Schirra "textbook" flight. Only three more passes stood between me and a routine landing off the bow of the *USS Kearsarge*. When I received the first indication that the sequencing system had malfunctioned a number of interesting experiments and systems evaluations had been completed, with just a few more to go. Then, with the sudden electrical anomaly and the sequence of events which followed, I knew I had a job ahead of me. Unlike Scott's case, however, I had sufficient time to contemplate a plan of action and collaborate with the flight-control personnel on the ground. Their valuable assistance was instrumental in the completion of my successful retrofire, reentry, and landing.

Now that Mercury is over and we stand at the threshold of more ambitious programs, the lessons each of us have learned will be constant tools with which to accept and accomodate new developments. Mercury has been only a beginning for the seven of us. The job at hand is to work to meet our new challenge in space with the same enthusiasm that everyone exhibited throughout this program.

# V

# APPENDIXES

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# APPENDIX A

## TYPICAL DOCUMENTS PREPARED FOR MERCURY

This appendix contains a listing of the types of documents prepared for use in the control and reporting of Project Mercury. Most of these documents are not available for general distribution.

| *Type of document* | *Estimated number of different volumes of each type* | *Prepared by—* | *Remarks* |
|---|---|---|---|
| 1. Mission Rules | 8 | MSC | |
| 2. Technical Information Summary | 14 | MSC | |
| 3. Flight Plan | 4 | MSC | |
| 4. Mission Directive | 17 | MSC | All issued as working papers. |
| 5. Data Acquisition Plan | 13 | MSC | |
| 6. Instrument Calibrations | 23 | MSC | |
| 7. Recovery Documents | 27 | | |
| a. Recovery Operations | | | |
| b. Recovery Requirements | | | |
| c. General Information | | | |
| d. Recovery Procedures | | | |
| e. Operations Plan for Recovery Team. | | | |
| 8. Postlaunch Reports | 21 | MSC | Issued as working papers prior to MR–1 (7 issues). |
| 9. Working Papers | 134 | MSC | Includes Items 5 and 9. |
| 10. Technical Memorandums | 2 | MSC | |
| 11. Miscellaneous | 61 | | Includes items (a) through (d). |
| a. Schedule and Cost Analysis | 1 | | |
| b. Descriptive Synopsis of Project Mercury. | 1 | | |
| c. Articles for journals | 23 | | |
| d. Conference papers | 30 | | |
| e. Operational Requirements | 3 | | |
| 12. Documentary Film | 26 | MSC | |
| 13. Quarterly Reports | 20 | MSC | |
| 14. Flight Controller Handbook–1 | 14 | MSC | |
| 15. Flight Controller Handbook–2 | 6 | MSC | |
| 16. Consolidated Remote Site Report | 6 | MSC | |
| 17. Mercury-Redstone Monthly Status Report | 12 | MSFC | |
| 18. Master Operational Schedule | 4 | MSFC | |
| 19. Complete Firing Test Report (5 parts) | 4 | MSFC | |
| 20. Operations Procedures | 2 | GSFC | |
| 21. Network Countdown | 5 | GSFC | |
| 22. Communications Operations Procedure | 2 | GSFC | |

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| *Type of document* | *Estimated number of different volumes of each type* | *Prepared by—* | *Remarks* |
|---|---|---|---|
| 23. Network Performance Report | 3 | GSFC | |
| 24. Network Operation Directive | 1 | GSFC | |
| 25. Test Requests, covering such items as: vibration, shock, heating, systems tests, destruction tests, accoustical tests, Project Orbit, functional tests. | 1, 125 | Contractors | |
| 26. Drawings (spacecraft) | >1, 800 (3, 200 pages) | McDonnell Aircraft Corp. | Does not include revisions. |
| 27. Formal Report Releases | 200 | McDonnell Aircraft Corp. | Includes items (a) through (e). |
| a. Spacecraft configuration | 20 | ---------- | For each spacecraft. |
| b. Failure Summary Report | 41 | | |
| c. Full Scale Simulated Mission Test. | 25 | | |
| d. Contractor Furnished Equipment Status Report. | 1 | ---------- | Periodically revised. |
| e. Other | 128 | | |
| 28. Service Engineering Department Reports ((SEDR). | 444 | McDonnell Aircraft Corp. | Separate SEDR's were generally issued for each system and test for each spacecraft. |
| 29. Miscellaneous: | | | |
| a. Contracts (formal) | 85 | MSC | |
| b. Contract change proposals | 390 | McDonnell Aircraft Corp. | |
| 30. Detailed Test Objectives | 9 | Aerospace Corp. | |
| 31. Operations Requirements | 3 | Air Force Missile Test Center | |
| 32. Operations Directive | 2 | Convair/ Astronautics | |
| 33. Flight-Test Reports | 9 | | |

# APPENDIX B

## NASA CENTERS AND OTHER GOVERNMENT AGENCIES

This appendix contains a list of government agencies that supported Project Mercury.

NASA Headquarters, Washington, D.C., and the following NASA Centers participated in Project Mercury:

- Ames Research Center, Moffett Field, Calif.
- Flight Research Center, Edwards, Calif.
- Goddard Space Flight Center, Greenbelt, Md.
- Langley Research Center, Langley Station, Hampton, Va.
- Launch Operations Center, Cocoa Beach, Fla.
- Lewis Research Center, Cleveland, Ohio
- Manned Spacecraft Center, Houston, Tex.
- Marshall Space Flight Center, Huntsville, Ala.
- Wallops Station, Wallops Island, Va.

Department of Defense, Washington, D.C.:

- Space Systems Division, U.S. Air Force, Los Angeles, Calif.
- U.S. Navy, 5th Naval District Headquarters, Norfolk, Va.
- Arnold Engineering Development Center, Arnold Air Force Station, Tenn.
- El Centro Naval Parachute Test Facility, El Centro, Calif.
- Naval Air Development Center, Johnsville, Pa.
- Wright Air Development Center, Wright-Patterson Air Force Base, Ohio
- Air Force Missile Development Center, Holloman Air Force Base, N. Mex.
- Naval Ordnance Test Station, Pensacola, Calif.
- Pensacola Naval Air Station, Pensacola, Fla.
- Air Proving Ground Center, Eglin Air Force Base, Fla.
- Army Ballistic Missile Agency, Redstone Arsenal, Ala.
- U.S. Army Transportation Command, Ft. Eustis, Newport News, Va.
- U.S. Marine Corps Air Station, Cherry Point, N.C.
- Military Air Transport Sciences, Dover, Del.
- White Sands Missile Test Center, White Sands, N. Mex.
- Pacific Missile Range, Point Mugu, Calif.
- Naval Air Station, Corpus Christi, Tex.
- Atlantic Missile Range, Cape Canaveral, Fla.

State Department, Washington, D.C.

Weather Bureau, Washington, D.C.

Aeronautic Chart and Information Center, St. Louis, Mo.

Public Health Service, Washington, D.C.

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# APPENDIX C

## PRIME CONTRACTORS

This appendix contains a list of the prime contractors for Project Mercury.

Aerospace Corp., El Segundo, Calif.
Chrysler Corporation, Highland Park, Mich.
General Dynamics/Astronautics, San Diego, Calif.
General Electric Co., Schenectady, N.Y.
Burroughs Corp., Detroit, Mich.
The B. F. Goodrich Co., Akron, Ohio
McDonnell Aircraft Corporation, St. Louis, Mo.
North American Aviation, Inc., El Segundo, Calif.
Pan American World Airways, Inc., Guided Missiles Range Division, Patrick Air Force Base, Fla.
Philco Corporation, Philadelphia, Pa.
Thiokol Chemical Corporation, Bristol, Pa.
Western Electric Company, Inc., New York, N.Y.

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# APPENDIX D

## SUBCONTRACTORS AND VENDORS

This appendix contains a list of Project Mercury spacecraft subcontractors and vendors that had contracts totaling more than $25,000:

AiResearch Manufacturing Co., Los Angeles, Calif.
Airwork Corp., Miami, Fla.
American Welding and Manufacturing Co., Warren, Ohio
Ampex Corp., Redwood City, Calif.
Applied Electronics Corp., Metuchen, N.J.
Arnoux Corp., Los Angeles, Calif.
Atlantic Research Corp., Arcadia, Calif.
Barnes Engineering Co., Stamford, Conn.
Beckman and Whitley, Inc., San Carlos, Calif.
Beckman Instruments, Inc., Berkeley Div., Fullerton, Calif.
Bell Aerosystems Co., Div. of Bell Aerospace, Buffalo, N.Y.
The Bendix Corporation, Utica Division, Utica, N.Y.
Bohanan Manufacturing Co., Falcon Field, Mesa, Ariz.
Brush Beryllium Co., Cleveland, Ohio
Burton Manufacturing Co., North Ridge, Calif.
CTL Division of Studebaker-Packard Corp., Cincinnati, Ohio
Cannon Electric Co., Salem, Mass.
Cannon-Muskegon Corp., Muskegon, Mich.
Carlton Forge Works, Paramount, Calif.
Collins Radio Co., Chicago, Ill.
The Connecticut Hard Rubber Co., New Haven, Conn.
Consolidated Electrodynamics Corp., Pasadena, Calif.
Consolidated Vacuum Corp., Rochester, N.Y.
Corning Glass Works, Chicago, Ill.
Crucible Steel Co. of America, Pittsburgh, Pa.
Custom Printing Company, Ferguson, Mo.
DeHavilland Aircraft of Canada Ltd., Downsview, Ont.
Dit-MCO, Inc., Kansas City, Mo.
Donner Division, Systron-Donner Corp., Concord, Calif.
Dorsett Electronics Laboratories, Inc., Norman, Okla.
Dynamic Research, Inc., Los Angeles, Calif.
The Eagle-Picher Co., St. Louis, Mo.
Electro-Mechanical Research, Inc., Sarasota, Fla., and Princeton, N.J.
Electronic Associates, Inc., New York, N.Y.
Electronic Wholesalers, Inc., Melbourne, Fla.
Emerson Electric Manufacturing Co., St. Louis, Mo.
Endenco Corporation, Los Angeles, Calif.
F. M. C. Corp., Buffalo, N.Y.
Fairchild Camera and Instrument Corp., Cable Division, Joplin, Mo.
Filtors, Inc., E. Northport LI., N.Y.
General Devices, Inc., Princeton, N.J.
Gulton Industries, Metuchen, N.J.
Harris Manufacturing Co., St. Louis, Mo.
Haynes Stellite Co., Chicago, Ill.
Hurletron, Inc., Control Products Division, Wheaton, Ill.
Interelectronics Corp., New York, N.Y.
Johns Manville Sales Corp., Chicago, Ill.
Walter Kidde and Co., Inc., Chicago, Ill.
Kollsman Instrument Co., Elmhurst, N.Y.
Leach Corp., San Marino, Calif.
Linde Co., Chicago, Ill.
Lockheed Propulsion Co., Redlands, Calif.
J. A. Maurer, Inc., Long Island City, N.Y.
D. B. Milliken Co., Arcadia, Calif.
M. B. Electronics, Div. of Textron Electronics, New Haven, Conn.
Minneapolis-Honeywell Regulator Co., Boston Division, Boston, Mass.

Minneapolis-Honeywell Regulator Co., Aeronautical Division, Minneapolis, Minn. (2 locations)
Missouri Metal Shaping Co., Overland, Mo.
National Car Rental, Sarasota, Fla.
National Water Lift Co., Kalamazoo, Mich.
Olin-Mathieson Chemical Corp., Winchester Western Div., Eastern Alton, Ill., and Baltimore, Md.
The Perkin-Elmer Corp., Norwalk, Conn.
Radioplane, Division of Northrop, Van Nuys, Calif.
Raymond Engineering Laboratory, Middleton, Conn.
Rock County National Bank, Janesville, Wis.
Schmelig Construction Co., St. Louis, Mo.
Selb Manufacturing Co., St. Louis, Mo.
Southwest Truck Body Co., St. Louis, Mo.
Tarco, Inc., Santa Monica, Calif.
Teleflex, Inc., Philadelphia, Pa.
Thiokol Chemical Corp., Elkton Div., New York, N.Y.
Thompson Ramo Wooldridge, Inc., Cleveland, Ohio
Titanium Metals Corp. of America, New York, N.Y.
Unidynamics, A Division of Universal Match Corp., St. Louis, Mo.
United Aerospace Div. of United Electrodynamics, Inc., Pasadena, Calif.
Waltham Precision Instrument Co., Inc., Waltham, Mass.

# APPENDIX E

## NASA PERSONNEL WHO PARTICIPATED IN PROJECT MERCURY

This appendix contains a listing of NASA personnel that contributed to the Mercury Project and represents the best effort possible to obtain a complete listing; however, it is known that some names are missing, such as people from the Langley Research Center. Those contributors whose names are missing are recognized as a group.

Ackerman, Sylvester J.
Actor, J. Paul
Adams, Robert S.
Adams, Ruth Ann
Adams, Walter I.
Adkins, James E., Jr.
Aiken, Donna S.
Aldrich, Arnold D.
Aldridge, Roy C.
Alexander, James D.
Alexander, Nancy C.
Alexander, W. Carter
Algranti, Annebell
Algranti, Joseph S.
Allaback, Wilber
Allen, Charlie C.
Allen, David J., Jr.
Allen, Elizabeth D.
Allen, Louis D.
Allen, Thomas H., Jr.
Allen, Vera J.
Allison, Howard J.
Anastos, Steve
Anderson, Donald W.
Appel, Margaret C.
Arabian, Donald B.
Arbic, Richard G.
Ard, Elizabeth H.
Armistead, Lucille B.
Armitage, Peter J.
Armstrong, Carol A.
Armstrong, Curtis S.
Armstrong, Dale E.
Armstrong, Geri
Armstrong, Lawrence D.
Armstrong, Stephen
Armstrong, William O.
Arnette, Sandra A.
Arnold, James P.
Arslanian, John G.
Arthur, James S.
Ashe, Gloria Jean
Ashley, Fancine
Askew, Abner N.
Assadourian, Arthur
Atamanchuk, Ivan J.
Atkins, Jones, Jr.
Augerson, William J.
Ault, John W., Jr.
Avery, John J., Jr.
Babola, Robert J.
Bailey, Charles L., Jr.
Bailey, E. Lou
Bailey, Frederick J., Jr.
Bailey, Glenn F.
Bailey, James W.
Bailey, John R.
Bailey, Norman R.
Bailey, Robert J.
Baillie, Richard F.
Baker, Ben R.
Baker, Robert L.
Balinas, Verby Lee
Balisky, Eileen M.
Ball, George D.
Ball, William R.
Ballas, Bebe B.
Banks, Harold H.
Banks, Judith Bower
Barker, Edward S.
Barker, Joseph T.
Barkley, Garland B.
Barnard, Jack
Barnes, Harold F.
Barnes, Lyndon S.
Barnett, James H., Jr.
Barney, Walter F.
Barrow, John M.
Barsky, Jerome
Barton, Ruth A.
Bates, James Richard
Battaglia, Harold F.
Battin, Richard B.
Baum, Herman
Beach, Mary
Beane, Patricia B.
Beatty, Lamarr D.
Beck, Harold D.
Beck, Jeanette H.
Becker, Robert W.
Beckman, David A.
Beddingfield, Samuel T.
Beerman, Rebecca
Beers, Charles A.
Beeson, Willirie M.
Begnaud, Ellis L.
Behuncik, John A.
Bell, Anita S.
Bell, Daniel M.
Bell, John
Bell, Larry E.
Bell, Lawrence Wilson
Bender, David
Bennett, James A.
Bennett, Marvin L.
Benson, Donald D.
Benson, Richard B., Jr.
Bergman, Clayton M.
Bergtholdt, Charles P. I.
Bernardin, Robert M.
Berney, Kathryn C.
Bernstein, Ruth
Berry, Dr. Charles A.
Berry, Ronald Lewis
Bertram, Emil P.
Bias, A. Dell
Biggs, Charles
Billingham, John
Bilodeau, James W.
Bishop, Halley M.
Bivens, Virginia T.
Black, Dugald O.
Black, Thomas
Blackwood, Howard F., Jr.
Blakemore, Thomas L., Jr.
Blance, Lucille

Blanchard, Robert S.
Blanco, J. A.
Bland, William M., Jr.
Blankenbaker, Lloyd
Blanton, Fred B.
Blanton, Lelia M.
Blase, William A.
Blevins, Edwin K.
Blue, Barbara
Blume, Donald D.
Blumentritt, James
Bobik, Joseph M.
Bobo, Leonard F.
Bobola, Robert E.
Bodmer, James E.
Bogart, William M.
Boler, L. Joseph
Bond, Aleck C.
Bond, Arthur C., Jr.
Bone, Eric Dale
Bone, James E.
Bonham, Robert L., Jr.
Booher, Cletis R.
Boozer, Becky
Bopp, Marlin Leroy
Borgman, Elsa M.
Borgman, Richard R.
Boring, James W.
Bostick, Jerry C.
Bostick, Linda T.
Bost, James E.
Boswick, Guy W., Jr.
Bosworth, George L.
Bothmer, Clyde B.
Bott, Barbara E.
Bowen, Maureen E.
Bowman, Melvin D.
Bowman, Robert A.
Boyce, William M.
Boyd, Robert
Boydston, Donald L.
Boykin, Wilbur R.
Boynton, John H.
Bracey, Gerald W.
Bradford, Halley, Jr.
Bradford, William C.
Bradley, Raymond H.
Brady, James T.
Branscomb, Albert L., Jr.
Braquet, Louto J., Jr.
Braslow, Myrtle S.
Braun, Alois, Jr.
Braun, Jane D.
Bray, Donald O.
Bray, Julia F.
Brent, Mary Sue
Brenton, Westley H.
Brewer, Mary H.
Brewer, Gerald W.
Brickel, James R.
Briggs, Thomas
Brigham, Richens E.
Brinkman, John
Britt, Leon E.
Britt, Malcolm V.
Broadwell, James D.
Brock, Eugene H.
Broman, Roseanna A.
Brooks, Laura A.
Brooks, Melvin F.
Brooks, Russell G.
Broome, Douglas R.
Broughton, Thomas G., Jr.
Broussard, Marcus J.
Brown, Beverly P.
Brown, Constance G.
Brown, David
Brown, Doris J.
Brown, James T.
Brown, J. Robert
Brown, Richard L., Sr.
Brown, Shirley A.
Brown, Timothy Murphy
Brown, Woodridge C.
Browne, Robert A.
Brownstein, Herbert
Bruce, David F.
Bruce, D. Jean K.
Bruemmer, Carline M.
Brumberg, Dolores
Brumberg, Paul G.
Brums, Dr. Rudolf H.
Bryan, Catherine C.
Bryan, Comer B., Jr.
Bryan, Doris E.
Bryan, Frank G.
Bryant, George K.
Bryant, John P.
Bryant, William C.
Byrne, Frank
Buck, Ann L.
Buck, Kenneth J.
Buckley, Charles L., Jr.
Buckley, Robert Hunt
Buller, Elmer H.
Bullock, Edward C.
Burbank, LaRue W.
Burbank, Paige
Burge, Betty Shelton
Burgeson, Frances
Burgess, James A.
Burgh, Anabel
Burke, Richard J.
Burkett, James E.
Burton, Mary Shepherd
Burton, Walter G., Jr.
Busch, Arthur M.
Bush, William H., Jr.
Bushong, Wilton E.
Butler, Walter Emmett
Butler, Wilbur E.
Butterworth, Ronald C.
Byer, David L.
Byrnes, Martin A., Jr.
Byrum, Doris
Cagle, Jewel J.
Cain, James L., Jr.
Caldwell, Ernest S.
Call, Dale W.
Callaway, Shirley L.
Calloway, Willis G.
Calonna, Richard
Calvillo, Efren
Camady, John E.
Cameron, Winifred S.
Camp, Howard C.
Campagna, G. Edward
Campbell, Jack A.
Campbell, Janet S.
Campbell, Jewel T.
Campbell, Marianne C.
Campbell, Melvin E.
Cannon, William L.
Canright, Richard B.
Capo, Raymond V.
Capps, Charles H.
Carbaugh, James P.
Carley, Richard R.
Carlson, Robert L.
Carmines, Sidney D.
Carpenter, Edward A.
Carpenter, Malcom S.
Carr, Ronald
Carroll, James B.
Carson, June M.
Carson, Thomas M.
Carter, Dan S., Jr.
Carter, Elmer J., Jr.
Carter, Nancy K.
Carter, Rosemary
Carter, Thomas F., Jr.
Case, Darlene D.
Casey, Francis W., Jr.
Casey, L. O.
Cash, Wanda
Cashion, Kenneth D.
Cason, Barbara L.
Cassels, George A.
Cassetti, Marlowe D.
Catloth, Mary M.
Catron, Dora B.
Catterson, Dr. Duane
Cerven, James C.
Cessac, Robert J.
Chalkley, Lois G.
Chamberlin, James A.
Chambers, Jerome P.
Chambers, Milton
Chambers, Thomas V.
Chandler, Amie F.

Chandler, William
Chandler, William O., Jr.
Chaplick, Robert G.
Chapman, Arthur C.
Chaput, Paul Theodore
Charlesworth, Clifford E.
Charters, Richard E.
Chase, William Raymond
Chauvin, Leo T.
Chauvin, Theodore T.
Cheatham, Donald C.
Chicoine, Ervin L.
Childers, Frank M.
Childs, Dewey L., Jr.
Chilton, Robert G.
Chitwood, Willie N.
Chop, Al
Christman, Laurence M.
Christopher, Kenneth W.
Christopher, Maxwell G.
Claffey, Patricia L.
Clark, Bobbie W.
Clark, Howard E.
Clark, Robert H.
Clark, Stewart
Clarke, J. C.
Clary, Charles D.
Clason, Robert M.
Clay, Russell P.
Clayton, Elden G.
Clayton, Mance S.
Clemence, Raymond R., Jr.
Clemens, Joan
Clements, Henry E.
Clements, James R.
Clemmons, Margaret D.
Clever, Edwin C.
Clickner, Russel E., Jr.
Cline, Jack S.
Clinton, Thomas S.
Coats, Boyd R.
Cochran, Harold W.
Cobb, James B.
Coble, Bill M.
Cockerham, Earl D.
Coe, Frank S., III
Coffman, Sandra B.
Cofield, John T.
Cohen, Jack
Cohen, Robert
Cohen, William
Cohn, Stanley H.
Cole, Charles W.
Coleman, Donald J.
Coleman, Mary R.
Coler, Charles
Coley, Patsy M.
Colleps, Dorothy
Collier, Frank
Collins, Curtis C.
Collins, Daniel D.
Collins, Dorothy
Collins, Harold G.
Collins, Walter E.
Collner, Joseph D.
Collura, Salvadore J.
Colonna, Diane
Colonna, Richard A.
Comer, Howard E., Jr.
Compton, Harold R.
Conley, James O.
Conlon, John W.
Conn, W. Jane
Connelly, Russell
Conner, Alfred L.
Conneway, Fred D.
Conrad, Ralph
Contella, Janice E.
Contella, Milton C.
Conversano, Andrew
Cooke, Arthur M.
Cooper, James
Cooper, LeRoy G., Jr.
Coppedge, Frank O.
Corbett, Bailey L., Jr.
Corbett, Gloria C.
Corbett, Wayne W.
Corcoran, Donald M.
Corey, Donna
Cormany, Charles A.
Cornelius, Paul T.
Corn, Graydon F.
Correale, James V.
Coston, Charles L.
Cottee, Gatha F.
Cotton, Paul E.
Cour-Palais, Burton G.
Covington, Clarke
Covington, Ozro M.
Cowan, John R.
Cox, Flo
Cox, Roy L.
Cox, William M.
Craighead, Paul T.
Crain, Doris J.
Crain, Josephine C.
Crain, Ronald L.
Crane, Luther L.
Craven, John P.
Creech, Norwood
Creighton, Henry C.
Cressman, John H.
Cribb, Herbert E.
Crichton, Frank M.
Criddle, William S.
Critzos, Chris C.
Critzos, O. Constance
Crone, Norman A.
Crow, Frank G.
Crow, Pauline G.
Crutcher, Thomas M.
Crowell, James L.
Crunk, Henry G., Jr.
Cumberworth, Gloria E.
Cunningham, Monte T.
Curlee, Harvey L., Jr.
Currie, C. Elsie
Curry, T. Bradley, Jr.
Dabbs, John H.
Dalby, James F.
Dalke, Edgar A.
Dall, C. E.
Dalton, Danny A.
Daniel, Tom H., Jr.
Daniels, Patricia A.
Dasilva, Anibal J.
Davenport, William H.
Davidson, William L.
Davids, Irving
Davis, Lawrence
Davis, Mary S.
Davis, Walter A.
Dawn, Frederic S.
Day, Joe L.
Day, Richard E.
Davidson, John C.
Davis, Leo P.
Davis, Philip W.
De La Portilla, Martha
De La Rosa, Herman J.
Dealy, Kathleen R.
Deagro, Richard P.
Dean, Kenneth J.
Deans, Philip M.
Deason, William P.
Debus, Dr. Kurt H.
Decamp, Royal D.
Decker, William E.
Deering, Ross E.
Deese, James H.
Deluca, Louis A.
Dement, Marvin Ernest
Deming, James E.
Dennis, William R.
Der Bing, William
Deshields, Shirley R.
Dessens, Charles Wayne
Devine, Robert G.
Devore, Phoncille
Dewell, William G.
Diaz, Rodolfo A.
Dibella, Josephine
Dickinson, John H.
Dickinson, William B.
Dickson, Ernest L.
Dietlein, Lawrence F.
Dills, Judith
Dingman, Reece
Disher, John H.
Dittmer, Dr. Daniel

Divone, Louis V.
Dixon, Ruth H.
Dobbs, John H.
Dobbs, Nancy Lynn
Dodd, Richard P.
Dodson, Joe W.
Donadio, Sullivan C.
Donaway, A. Inez
Donegan, James J., Jr.
Donnelly, Paul C.
D'Onofrio, Gus A.
Dotts, Homer
Dougherty, Raymond
Douglas, William K.
Dowling, Carlise W.
Downs, James E.
Doyle, Eugene L.
Driskill, Billie R.
Driver, Mary H.
Driver, W. B.
Drone, Benjamin R.
Drummond, William E.
Dryden, Dr. Hugh L.
Duck, Kenneth J.
Dudley, Brenda T.
Dudley, Nan Goode
Duggan, Orton L.
Duggins, Alberta D.
Dugoff, Leon
Dukes, Francis B.
Dumay, William Henry
Dungan, Larry J.
Dunning, Robert W.
Dunseith, Lynwood C.
Dupree, B.
Duret, Eugene L.
Durocher, Charlotte
Durrett, William Reuben
Dutton, Richard E.
Dyal, Lawrence E.
Easter, William B.
Eaton, Albert J.
Eckert, Charles J.
Eddington, Chester E.
Eddy, B. Eugene
Edelberg, Robert E.
Edmonds, Eugene
Edmondson, Florence M.
Edmondson, F. William
Edrington, John W., II
Edwards, Elwood S.
Edwards, Kermit A.
Edwards, Marion D., Jr.
Edwards, Thomas M.
Eiband, A. Martin
Eicher, Grace E.
Eickmeier, Alfred B.
Eickmeier, Lester R., Jr.
Eik-Nes, Kristen B. D.
Ekeroot, Stig
Elk, Jimmy R.
Eller, Joseph M.
Ellis, Anna Whiteside
Ellis, Wilbert Edward
Elms, Charles P.
Emily, Jerry
Enders, John H.
Enderson, Laurence W., Jr.
Engel, Jerome N.
Engvall, John L.
Enlow, Roger D.
Ensley, Betty M.
Epperly, James W.
Epperly, Virginia H.
Erb, Bryan R.
Ernull, Robert E.
Ertel, Ivan
Ertl, Emily M.
Erwin, Sue R.
Esenwein, George F.
Evans, Norma M.
Everline, Robert T.
Ewart, David D.
Ezell, Melvin
Faber, Stanley
Fagan, John E.
Faget, Maxime A.
Fahlstrom, Paul G.
Fairchild, John J., Jr.
Falbey, Iola M.
Fannin, Lionel E.
Farley, John S.
Farmer, Norman B.
Farrior, Leona
Faulk, Ryan J., Jr.
Feddersen, William E.
Fellows, Mary E.
Fergerson, Shirley J.
Ferguson, Barbara
Ferguson, Clarence
Ferguson, Gordon M.
Ferguson, Helen L.
Ferguson, Nellie G.
Ferguson, Paul O.
Ferguson, Richard B.
Fernandez, Joseph
Ferrall, Gordon B.
Fielder, Dennis E.
Fields, E. M.
Filipowski, John J.
Filley, Charles C.
Filley, Charles W.
Finn, James E.
Finley, Robert P.
Fiorentino, Kelly A.
Firth, Ruth R.
Fisher Emmitt E.
Fisher, Frankie
Fisher, Jackie L.
Fisher, Lewis R.
Fisher, Vernon E.
Fitch, David C.
Fitzgerald, Evelyn B.
Fitzgerald, Hugh D.
Fitzgerald, James J.
Fitzgerald, Norma B.
Fitzkee, Archie L.
Flanagan, James R.
Fletcher, Calvin B.
Flournoy, Walter
Foley, Helen N.
Folkes, Doris P.
Folkes, William G.
Folwell, Paul A., II
Forquer, Madeline H.
Foster, Galloway B., Jr.
Foster, Mary P.
Foster, Norman G.
Foster, Richard W.
Fout, Blanche H.
Fowler, James W.
Fowler, Joe
Fowler, John F.
Frandsen, Niels P.
Franklin, Arthur E.
Franklin, Darold Bernard
Franklin, George C.
Franklin, Marion R., Jr.
Frank, M. P.
Frasier, Cline W.
Frazier, Jesse C.
Frazier, Thomas W.
Frazier, Violet M.
Freedman, Gilbert M.
Freeman, Gil
Freeman, James R.
French, Burrell O.
French, Harold N.
French, John C.
Frere, John A.
Fridge, Ernest Marion III
Friloux, Henry J., Jr.
Frye, C. Lawrence
Fugler, Bartley A.
Fuller, Carolee Boykin
Fulmer, Otis, Jr.
Funderburg, Paul E.
Fulton, Jeanne S.
Fultz, Bennet M.
Funk, J.
Funkhouser, Robert B.
Gadow, Charles G.
Gaffney, Patrick S.
Galezowski, Stanley H.
Gallagher, Thomas F.
Gallagher, Virginia M.
Galloway, Sarah Helms
Gambill, Ilona G.
Gammon, Frank M.
Gans, Barbara

Gant, William L.
Gantz, B. R.
Garbacz, Michael
Gardner, Benson B.
Gardner, Virgil F., Jr.
Garino, Joe D., Jr.
Garland, Benjamine J.
Garner, Charles W.
Garner, Iris A.
Garrett, Arnold W.
Garrett, Crayton
Garrison, John C., Jr.
Garza, Alfred M.
Gaster, Barbara J.
Gaster, Jeanne
Gatchell, Herbert L.
Gates, Sally D.
Gaughan, David
Geddes, Leslie A.
Geier, Douglas J.
Geier, Robert
Geisler, Phyllis A.
Geller, Samuel
Gerber, David L.
Gerstle, John E., Jr.
Gfeller, Virgil A.
Gibbons, Howard
Gibbons, Jim L.
Gibbons, Thomas F.
Gibson, Pearl C.
Gibson, Thomas F.
Gifford, Burton M.
Giles, June A.
Gilkey, John E.
Gillespie, Ben
Gillespie, Warren
Gill, William L.
Gills, Sidney
Gilruth, Robert R.
Glenn, John H., Jr.
Glenny, Virginia T.
Glover, Kenneth E.
Glynn, Francis I. P.
Goad, John W.
Goldcamp, Thomas F.
Goldenbaum, David M.
Goldsmith, Verl A.
Goldstein, Stan
Gonzalez, Jose L.
Goodman, Jerry R.
Goodson, Adolph
Goodwin, Burney H.
Goodwin, Haskell J.
Goodwin, Mary Ann
Gordon, Bob
Gordon, Donald L.
Gorman, Robert E.
Gorman, T. P.
Goslee, John W.
Gottuso, Vincent J.
Grace, Thomas J.
Grafe, Robert L.
Graffe, Robert T.
Graham, Glenn W.
Graham, John B., Jr.
Graham, Ralph E.
Graham, William
Grames, H. Jack
Grammer, Donald B.
Grana, David C.
Grandfield, Allen L.
Granger, Harold E.
Grant, Charles M., Jr.
Graves, Barry
Gray, Wilbur H.
Green, Don
Green, M. Linda
Green, Robert N.
Greene, L. Annette
Greene, Merton D.
Greenfield, Sarah F.
Greenfield, Terry B.
Greenglass, Bertram
Gregory, Donald T.
Greil, Karl F.
Griffin, Bobby G.
Griffin, Charles H.
Griffin, Oscar F.
Griffin, Wesley W.
Grimes, Walter E.
Griffis, Carl L.
Griffith, Jack A.
Grimbly, Samuel C.
Grimes, Walter E.
Grimwood, Jim
Grissom, Virgil I.
Gross, Bernard D.
Gross, Harry G.
Gross, Stanley A.
Grow, R. Bruce
Grow, Emily H.
Gruene, Dr. Hans F.
Guice, Mildred L.
Guidry, Mark A., Jr.
Gunnersen, Alf S., Jr.
Gundersen, Robert T.
Gurley, John R., Jr.
Guthrie, Alfred E.
Guthrie, George C.
Guy, Judith
Guy, Walter W.
Gwinn, Ralph T.
Habron, Betty H.
Hackworth, Robie
Hagan, Mason
Hager, Mary C.
Hagood, Martin L.
Hairston, Ernest
Hall, Charles J.
Hall, Eldon W.
Hall, Dr. Harvey
Hall, James L.
Hall, John B., Jr.
Hamblett, Edward B., Jr.
Hamby, William H.
Hammack, Jerome B.
Hammer, Louis
Hammersmith, John
Hammock, David M.
Hammond, James P.
Hammond, Joseph W., Jr.
Hampton, Harold D.
Hand, Arthur A.
Haney, Francis J.
Hannigan, James E.
Hansen, Paul
Hardin, Donald W.
Hardin, William G.
Hardwin, William B.
Hargrave, Claude S.
Harper, Richard H.
Harper, Velda B.
Harrelson, Patsy Ann
Harrin, Eziaslav N.
Harrington, Nancy J.
Harrington, Robert D.
Harris, Carl B.
Harris, Emory F.
Harris, Fred A.
Harris, George, Jr.
Harris, Janet E.
Harris, Joe
Harris, John B.
Harris, Russell
Harris, Sylvia
Harrison, Floyd L.
Harrison, Margaret R.
Harrison, Rena B.
Hart, Robert F.
Hartlein, John
Hartung, Jack B.
Harvey, Gordon W.
Hassett, Raymond
Hathcock, Juanita
Hatton, George
Haugew, Kenneth R.
Havenstein, Paul L.
Hawk, Willard E.
Hawkins, George M., Jr.
Hawkins, I. Edna
Hayes, Leroy
Hayes, Leslie E.
Hayes, Neisel M.
Hayes, William C.
Haynes, James F.
Hays, Edward L.
Hays, Robert D.
Hearn, Chase P.
Heathcote, Dennis E., Jr.
Heather, Gerald D.

Heaton, Sydney N.
Heberlig, Jack C.
Heckelmoser, Charles J.
Heetderks, H. Richard
Hegwood, Robert B.
Hegwood, Sarah E.
Hehn, Joseph A.
Heidler, Homer F., Jr.
Heinlein, Marjorie J.
Heiser, Robert F.
Heitman, Erwin W.
Heller, Niles R.
Heller, Robert H.
Helterbran, Irene J.
Henderson, Grady P.
Henderson, Joseph D.
Henderson, Melba S.
Henderson, Sharon
Henderson, Thomas Harder
Hendrickson, Douglas R.
Henry, James P.
Hensley, James B.
Henson, Kirby
Herbert, Frank J.
Herbert, Herbert L.
Herring, Hugh S.
Herring, Robert W., Jr.
Herrman, Dorothy M.
Hershey, Theodore P.
Hessberg, Rufus
Hesson, Robert K.
Hester, Randolph H.
Hettinger, Fredric L.
Hibbs, William C.
Hicks, Claiborne R., Jr.
Hicks, Wilburn
Hiers, Harry K.
Hiers, James R.
Higgins, Rodney F.
Hightower, Libbie L.
Hill, Ann W.
Hill, Elizabeth J.
Hill, Harold H.
Hill, Lawrence E.
Hill, Ralph E.
Hill, Norma L.
Hiller, Mary Jo
Hilyer, Euell
Hinds, James J.
Hinds, Noble F.
Hinson, James K.
Hirst, Carolyn W.
Histand, Dorothy B.
Hjornevik, Wesley L.
Hock, Catherine
Hodge, B. Leon
Hodge, John D.
Hoff, Orlo
Hoffman, Ernest E.
Hoffman, John P.
Hoffman, Raphael F.
Hogan, Edward J.
Hogg, Carolyn
Hoggard, Walter C.
Hoisington, Jerry E.
Holden, Joan S.
Holland, John
Hollingsworth, Miles M.
Holloway, Tommy W.
Holman, Richard A.
Holmgren, Herbert L.
Holt, Richard L.
Holt, Talmadge W.
Holt, Thomas E.
Honicker, Candy B.
Hoover, Ida B.
Hoover, Luther L.
Hoover, Richard A.
Hopton, Conrad E.
Horsman, Paul F.
Horstmann, Robert W.
Horton, Caroline L.
Horton, Elmer A.
Horton, Eugene E., Jr.
Hough, Agnes S.
House, Edward G.
Howard, Carole A.
Howard, Lalah
Howell, Joseph J.
Howerton, John C.
Huffman, Bobby R.
Huffstetler, William J., Jr.
Huggins, Matilda M.
Hughes, Carroll V.
Hughes, Donald F.
Hughes, George H.
Hughes, Helen W.
Hughes, James
Hughes, Virginia B.
Hull, Anne L.
Humphrey, Francis S.
Humphrey, John T.
Humphrey, William R.
Hungall, Robert G.
Hunt, Gerald L.
Hunt, Hal
Hunt, Phyllis S.
Hunt, Shirley A.
Hunter, Daniel S.
Hurlbert, Alma Adams
Huss, Carl R.
Hutchens, Rachel B.
Hutchinson, Neil Barrie
Hux, Lillie R.
Hyle, Charles T.
Idomir, Kenneth
Incerto, Donald J.
Ingalls, Charles W., III
Ingels, Claude
Ireland, Fred H.
Irwin, Kenneth
Isley, William C.
Jaap, Fred S.
Jackson, Arnold B., Jr.
Jackson, Bruce G.
Jackson, Carmault B.
Jackson, James
Jackson, Margaret M.
Jacobs, Donald L.
Jacobs, Richard M.
Jacobs, Stephen
Jacobsen, Stanley
Jafferis, William
Jakir, N. S.
James, Frances L.
James John L., Jr.
Janokaitis, John, Jr.
Jarrett, Jaye C.
Jenke, Richard K.
Jenkins, Morris V.
Jenness, Martin D.
Jenness, Phyllis T.
Jensen, Louisa
Jesen, Willard G.
Jeter, John D.
Jevas, Nickolas
Jezewski, Donald J.
Johns, James A.
Johnson, Ann C.
Johnson, Bryant L.
Johnson, Caldwell C., Jr.
Johnson, Carl P.
Johnson, Carol L.
Johnson, Edward T.
Johnson, Edwin Cyril
Johnson, Elizabeth P.
Johnson, Francis, Jr.
Johnson, Harold I.
Johnson, Jane
Johnson, Jeanne
Johnson, John H.
Johnson, Kenneth L.
Johnson, R. E.
Johnson, Robert
Johnson, Suellyn
Johnson, Virginia W.
Johnson, W. Kemble
Johnston, Richard S.
Jollay, James H.
Jonas, Arthur
Jones, Enoch M.
Jones, Jack A.
Jones, Jeremy B.
Jones, Rosemary
Jones, Sidney C., Jr.
Jones, Z. Vance
Jordan, Adaran B.
Jordan, Carolyn
Jordan, Patricia L.
Jordan, Sandy

Jorolan, Albert E.
Jow, Josephine
Kadesch, Charles S.
Kaiser, Bena W.
Kammerman, Mary
Kanak, John M.
Kane, Beverly E.
Kaplet, Ruth P.
Kapryan, Walter J.
Karakulko, Witalij
Karberg, Elmer H.
Karick, Francis S.
Kase, Louise E.
Katchmore, Betty R.
Kaufman, Louis L.
Kavanaugh, Walter W.
Keathley, William H.
Keathly, William
Keck, Frank
Keegan, Evelyn P.
Keene, Bernard A.
Keene, Lester F.
Keffer, Clarence O.
Kehl, Robert P., Jr.
Keil, Esther
Keith, Ernest L.
Keller, James A.
Keller, Leonard
Kelley, William A.
Kelly, Ferdinand G.
Kelly, James R.
Kelly, Keith V.
Kelly, William R.
Kempainen, Leona L.
Kendall, Joseph
Kenerly, Barney G.
Kennedy, Daniel C.
Kennedy, E. Frances
Kennedy, Richard C.
Kent, Henri J.
Kent, Thomas, Jr.
Kerns, Carl Wesley
Kiehl, Paul F.
Kiker, John W.
Kilby, Ann B.
Kilgallen, Raymond F.
Killmer, George F., Jr.
Kinard, Martha Rebecca
Kincaide, Patricia N.
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King, Charlotte E.
King, Fred L.
King, John W.
Kinnaird, Oxley T.
Kinzler, Jack A.
Kirby, Ryborn Ray
Kirk, Albert Lawrence
Kirkpatrick, James C.
Klabosh, Charles
Kleinknecht, Kenneth S.
Kline, Robert T.
Klockmann, Robert K.
Kloetzer, Paul H.
Knapp, Joan R.
Knapp, William F.
Knauf, Col. George M.
Knell, Kenneth E.
Knepp, Judith R.
Knight, Gordan W.
Knothe, Dr. Adolf H.
Knox, Betty S.
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Konneker, Patti K.
Koons, Fred D.
Koons, Wayne E.
Koos, Richard H.
Kopcik, Donna J.
Koplin, James
Koplin, Joyce H.
Kornegay, John H. F.
Koslosky, John T.
Kosmo, Joseph J., Jr.
Koutsandreas, Peter
Kovitz, Carl J.
Kraft, Christopher C., Jr.
Krambo, Betty Jane
Kramer, Paul Clinton
Kranz, Eugene F.
Krasnican, Milan J.
Krause, Marilyn H.
Kreske, Doris S.
Kreske, Joseph
Krpec, Charles
Krueger, Mary L.
Kubasko, James J.
Kuehnel, Helmut A.
Kugel, Harold
Kyle, Howard C.
Lackey, Camille D.
Lackey, David J.
Labutka, Joseph R.
Lail, Margaret H.
Lafleur, Walter
Lamache, Andy
Lamay, Harold J.
Lamey, William C.
Lambert, Clarence C.
Lamonte, Robert J.
Lane, James Howard
Langford, John H.
Langosh, Eva K.
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Largent, Harold R.
Larson, Mark S.
Lasater, Jack
Lasure, Clarence R.
Laughlin, Dr. C. Patrick
Lauten, William T., Jr.
Lautzenheiser, Ernest G.
Lavigne, Adeline M.
Law, Fleming
Lawrence, Bernard W.
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Lawrence, Thelma
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Lea, Robert N.
Leach, Barney H.
Leach, Diane E.
Leatherman, Pattie S.
Leblanc, Curtis
Lechter, Sidney
Ledbetter, Otis W.
Lee, Arc F.
Lee, John B.
Lee, Lewis H.
Lee, Mark T., Jr.
Lee, Dr. William A.
Leech, Ted B.
Leech, Theodore
Leezer, Robert
Legg, Ruby L.
Lem, John
Lem, John D., Jr.
Lemay, Harold J.
Lemmon, Carl L.
Lemons, Eddie J.
Lendle, Joseph F.
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Leonard, Pauline O.
Leonard, Sylvia
Leopold, Louis
Leshko, John E.
Lesky, Edward S.
Leslie, Claude E.
Lewis, Charles R.
Lewis, James L.
Lewis, John H., Jr.
Lewis, Louise B.
Lewis, Martha Camp
Liccini, Luke L.
Lichtey, Donald H.
Liddy, Joan M.
Liddell, John J.
Liebau, Charles R.
Lightsey, Alfred E.
Lill, Joseph C.
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Lineberry, Edgar C., Jr.
Link, Dr. Mae
Link, Patricia D.
Linn, Daniel
Linn, Kathryn E.
Lippitt, Maxwell W., Jr.
Lishman, Penny P.
Little, George Watkins
Littlehales, Mary C.

Lizcano, Ester R.
Llewellyn, John S., Jr.
Lobb, John D., Jr.
Lockard, Daniel T.
Lockard, Miles L.
Locke, Vandiver
Logan, Harry K.
Lohner, Anton, Jr.
Long, James L.
Long, Robert G.
Loomis, Leonard W.
Lopez, Mary F.
Loranzo, Arturo T.
Lord, Douglas R.
Lord, Harold W.
Lorenzen, Gerald A.
Lovan, James G., Jr.
Lovejoy, William L.
Low, George M.
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Lowe, John B.
Lowe, Joyce T.
Lowe, Nancy C.
Lowman, Dr. Paul D.
Luker, Nephi M.
Lowry, Bryce W.
Lowry, Dr. Rom
Lucas, Dick Manton
Lucas, Majorie Frye
Lucas, Paul V.
Lucas, William A.
Lumsden, Elmer G.
Lunney, Glynn S.
Lusby, George W.
Lutz, Charles C.
Lytle, Carroll D.
MacDougall, George F., Jr.
Magin, Roy L.
Mahone, Mildred A.
Maillet, Louise H.
Maimes, Howard G.
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Maloney, Philip R.
Malpass, Wendell
Mann, Everette S.
Mannen, Patricia
Mansberg, Gerald
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Marak, Ralph J.
Marek, Raymond
Marbach, James R.
Markley, J. Thomas
Markos, Athena T.
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Marn, Joe D.
Maronde, Del R.
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Marsh, Louise K.
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Martinkovic, Carol Ann
Martin, Shell E.
Martin, Thomas E.
Martin, Virginia A.
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Mathews, Charles W.
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Matthews, Hayword E., Jr.
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Maynard, Owen E.
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Mayo, Richard
Mays, Jackie D.
McBarron, James W., II
McBrayer. Robert O.
McCafferty, Riley D.
McCann, Robert R.
McConnell, James R.
McCown, Weldon B.
McCoy, Hugh E., Jr.
McCreary, Ben F.
McCurley, John H.
McCurry, Ollie E.
McCutcheon, Ernest P.
McElwee, Edward M.
McHenry, Jessie P.
McKay, Scott S., II
McMillan, Aron
McCollum, Marcia H.
McCrurey, Geneva E.
McGuire, Charles W.
McKee, Daniel D.
McCarthy, Bill J.
McCleece, Howard M.
McClendon, Mary Lou
McCloud, Mary W.
McCoy, Hugh E.
McCracken, Roberta A.
McCraw, D.
McCreary, B. F.
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McDonald, Imogene C.
McDonnel, Robert H.
McDougall, G. F.
McDowell, James W.
McElyea, Bennie A.
McGeen, Bernard J.
McGuire, Charles W.
McGuire, Peggy D.
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McKaskle, Verdie M.
McKee, Charles W.
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McKim, W. P.
McKinsey, Cynthia L.
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McLaughlin, George W.
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McMahan, M. Irene
McMann, Harold J.
McMath, Daniel C., Jr.
McMillion, Lee N.
McMurry, William C., Jr.
McNeece, James E.
McTavish, Charles J.
Meade, Nora H.
Meadows, May T.
Medina, Pete
Meeks, Emory J.
Mehailescu, George J.
Meintel, Alfred J., Jr.
Melga, Roy
Melton, Riley P.
Mendoza, Ted
Mengel, John T.
Mercer, Jinx
Mercer, Robert D.
Merchant, Ernestine C.
Merritt, Fred V.
Mersereau, Ann
Messier, Roger N.
Mething, Raymond H.
Meyer, Andre J., Jr.
Meyer, Grayden F.
Meyer, William R.
Michael, Ed
Michael, James M.
Michel, Edward L.
Middleton, William A., II
Miller, Arthur, Jr.
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Miller, Blanche D.
Miller, Douglas H.
Miller, Harold G.
Miller, Henry W.
Miller, Robert D.
Miller, Ruth T.
Mills, Blanche H.
Mills, Ronald W.
Mills, Wayne L.
Minderman, Peter A.
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Minster, John E.
Minter, John B.
Mire, John L.
Mitchel, Harry
Mitchell, Arlene R.
Mitchell, John P.
Mitchell, Junior M.
Mitchell, Virden M.
Mitscherling, Mary A.

Mixson, Meryle W.
Mockbee, Jean
Monfalcone, Delores A.
Monroe, Tallulah T.
Montgomery, Carole A.
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Moor, Joel W., Jr.
Moore, Alan Joseph
Moore, Arthur H.
Moore, Dale E.
Moore, Frances A.
Moore, Gladys C.
Moore, James S.
Moore, Rebecca
Moore, Rose M.
Moore, Sarah H.
Moore, Thomas E.
Morewitz, Alvin H.
Morris, David P., Jr.
Morris, Dowsie W., Jr.
Morris, Norman S.
Morrison, Ned
Morrison, Nellie
Morrow, Lola H.
Morse, Archibald E., Jr.
Morton, John W.
Moseley, William A.
Moseley, William C., Jr.
Moser, Jacob C.
Moser, Robert E., Jr.
Moses, Claude S., Jr.
Muchinsky, Lawrence
Muhly, William C.
Mulcahey, William T., Jr.
Munford, Robert E.
Mungall, Robert G.
Murphy, James F:
Murphy, Richard
Murphy, Thomas P.
Murray, Charles S.
Murray, George W.
Muse, Gene F.
Musil, Mildred V.
Myer, Sheila J.
Myles, David T., Jr.
Myrsten, Antonette T.
Nagy, Alex P.
Nagle, Charles C.
Nagle, Margaret
Nanz, Robert A.
Nassiff, Samuel H.
Nau, Rowena S.
Neal, James L.
Nelms, Nick
Nelson, Clair D.
Nelson, Donald A.
Nelson, Helen G.
Nelson, Morris C.
Nelson, Richard David
Nersesian, Richard R.
Nesbitt, William J.
Ness, Harold J.
Ness, Lawrence A.
Newall, Robert
Newgent, Joyce L.
Newman Frank B.
Newman, Geraldine H.
Nicaise, Patricia A.
Nichols, Daniel G.
Nichols, Ralph E.
Nichols, Donald L.
Nichols, Lee R.
Nieman, Ed
Nies, Charles B.
Nolan, James P., Jr.
Noll, Jean F.
Nonamaker, Laura S.
Nordstrom, John R.
North, Warren J.
Norton, Albert T.
Nuttall, John C.
O'Briant, Thomas E.
Odenwalder, Edgar P., Jr.
Oglesby, Theodore L.
Ohnesorge, Thomas E.
Okand, Kazuo Fred
Okeefe, Dr. John A.
Olasky, Charles C., Jr.
Oloughlin, Carol R.
Oloughlin, John C.
Olsen, Aaron B.
Oneal, Robert L.
O'Neill, James E.
Orman, Donald L.
Osgood, Catherine T.
Osgood, Donald R.
Ostrander, Robert F.
Ottinger, Jack
Ould, Wallace
Owen, Murline L., Jr.
Owen, Robert
Owens, Marion C.
Owens, Mary S.
Pace, Charles W.
Packard, Calvin A.
Packham, Leonard E.
Pairque, Hildred B.
Panizza, John R.
Pantano, Stephen T.
Pantoliano, Thomas D.
Parker, Carl
Parker, Clarence O.
Parker, Dorothy J.
Parker George H.
Parker, Michael C.
Parker, Robert N.
Parks, Francis G.
Parsons, Nelson D.
Parsons, Walter E.
Parmenter, Frank
Parten, Richard P.
Pashby, Paul J.
Patnesky, Andrew
Patterson, Charles W.
Pavlosky, James E.
Payne, Stanley C.
Peake, Robert L.
Pearce, Fred T., Jr.
Peele, Theresa M.
Peerboom, Robert
Pendley, David D.
Penland, Dennis T.
Pennington, John B.
Pereboom, Robert L.
Perkins, E. Franklin
Perkinson, John A.
Perlmutter, Robert
Perreten, David E.
Perry, Donald M., Jr.
Perry, Harold Ethelbert
Pesman, Gerard J.
Peters, Karl G.
Peters, Stanley, Jr.
Peterson, Jean L.
Peterson, John J.
Pettit, Richard V.
Petynia, William W.
Peytonel, Milton
Pfau, Robert W.
Pfeiffer, William A.
Phelps, Ellsworth, Jr.
Phifer, Judy G.
Phillips, Donald E.
Phillips, Emmett
Phillips, Franklyn W.
Phillips, Paul J.
Phlieger, Graydon A., Jr.
Pickett, Andrew J.
Picos, Marvin N.
Pierce, Bobby J.
Piland, Joseph V.
Piland, Robert O.
Pinson, Vestor L.
Pitt, Patricia
Pittman, James D.
Pitts, Joseph B.
Platt, William E.
Plaumann, Robert H.
Plunkett, Robert A.
Pollard, Dr. Richard
Pond, Margaret B.
Poole, Richard B.
Poole, Walter L.
Pordon, Ellen
Porten, Rita
Porter, Diana S.
Porter, Harry
Posavec, Catherine T.
Powell, Alice J.
Powell, Doris E.

Pratt, Billy W.
Preston, G. Merritt
Preston, Richard K.
Price, Donald F.
Price, Thomas G.
Prim, James W., III
Prince, Robert N.
Prine, Elbert
Privette, James E., III
Proctor, LeRoy, Jr.
Proferes, Constantine Gus
Prothman, Lillian V.
Purser, Paul E.
Quarterman, Wallace L.
Quayle, Howard G.
Quinn, Edith O.
Quinn, Joseph R.
Rabren, Robert B.
Radford, George E.
Radnofsky, Matthew I.
Rafel, Norman
Rainwater, Wallis C.
Raley, Eldon O.
Rall, Paul M.
Ramey, William P.
Raney, James L.
Rann, John A.
Rapp, Rita M.
Rasberry, James R.
Rasco, Woodrow W.
Rasnick, Thomas W.
Rathburn, Donald Ford
Rayfield, John F.
Razwich, Irene M.
Ream, Harold E.
Reardon, Lester D.
Reaves, Ollie M.
Redfield, Marvin
Reed, Gene A.
Reed, Dr. John H., Jr.
Reed, Lettie B.
Reid, Doris W.
Reini, William A.
Regelbrugge, Robert R.
Remely, Rosemarie R.
Remson, O. James
Reumont, Maurice R.
Reveley, Madeline F.
Reveley, William F.
Revell, Ruth S.
Revels, Antoinette P.
Rexroad, Eva O.
Reyer, Bobby G.
Rial, Joseph K.
Richard, Louie Gene
Richards, Gary M.
Richards, Stanley R.
Rideout, Janet H.
Ridley, Edna R.
Ried, Robert C., Jr.
Riegert, Daniel
Rigell, Ison A.
Riley, Phyllis E.
Rinecker, Franz Georg
Rippstein, Wayland J., Jr.
Risler, Welby T.
Risso, William P.
Ritch, Robert E.
Rivers, James E.
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Roach, Jones W.
Roach, Leo O., Jr.
Roane, Mary
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Robbins, Howard
Robbins, Rosaleigh M.
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Roberts, Eugene
Roberts, Glenn B.
Roberts, John E., Jr.
Roberts, Tecwyn
Robertson, Duane E.
Robertson, Norman E.
Robins, C. Howard, Jr.
Robins, Joyce F.
Robinson, Bertly
Robinson, Glover H.
Robinson, Peter J.
Robinson, Ray
Rochford, Alan M.
Rodriguez, Emilio Jr.
Rogers, Charlie E., Jr.
Rogers, Christine M.
Rogers, Ernest R.
Rogers, William F.
Rollins, Robert H. III
Rose, James T.
Rose, Rodney G.
Rosen, Milton W.
Rosenbaum, Alan Charles
Rosenbaum, Floyd W.
Rosenberg, Frank T.
Rosenberry, John
Ross, Edward A.
Ross, Mildred C.
Rosser, David C.
Roth, Carl E.
Roth, Janet S.
Roth, John A.
Rouiller, Charles A., Jr.
Rouse, Carroll R.
Roush, George Bernard
Rowell, Steiner L.
Rudolph, Pauline B.
Ruffin, Rene F.
Ruff, George E.
Ruggeri, Ann L.
Russell, Howard
Russell, J. B.
Russell, Libreda B.
Russo, James F.
Rutland, James M.
Sachen, Richard J.
Saecker, Albert J.
Saieg, Richard L.
Salmanson, Jay A.
Salyer, Walter D.
Salzberg, Irving M.
Samonski, Frank H., Jr.
Samonski, Joan P.
Sanders, Roger H.
Sandige, Carolyn W.
Sandridge, Richard A.
Sargent, John D.
Sarlis, Catherine
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Saucer, Dr. Rayford T.
Saunders, James F., Jr.
Saunders, Nannie L.
Savage, Melvyn
Sawyer, Barbara E.
Sawyer, Diane F.
Sawyer, O. McCoy, Jr.
Sawyer, Ralph S.
Sayers, Robert
Sayler, J. O.
Schaefer, Lola S.
Schaibley, John R.
Scheetz, Carlton F.
Scherer, Harris F., Jr.
Scheuerman, Hugo P.
Scheurmann, Henry
Schiesser, Emil R.
Schiller, Barbara A.
Schirra, Walter M., Jr.
Schisser, Glenna
Schler, Morton
Schlottman, Paul W., Jr.
Schmidt, Richard A.
Schmitt, Arthur L.
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Schnarte, Dave
Schneider, Harold
Schnell, Doran E.
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Schoch, Robert H.
Schuiling, Roelof L.
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Schultz, Sandra C.
Schulz, Raymond Henry
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Schwartz, Daniel E.
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Scott, Edwin C.
Scott, Iva L.
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Scrivener, Nina O.
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Secreti, Eugene J.
Segota, Mary P.
Segota, Peter
Seigel, David
Seille, Mary A.
Selby, LeRoy, Jr.
Seligman, Margo S.
Semmons, Mary
Sendler, Karl
Shankle, Ralph
Shankles, Thyra K.
Shannon, Autumn Y.
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Shaper, Sue Z.
Sharma, Herman S.
Shaw, Nathaniel
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Shelton, Loyd C.
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Shepard, Alan B., Jr.
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Shillito, Thomas
Shimshock, Leo J.
Shinkle, Frank J.
Shirk, Nancy M.
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Shoaf, Harry C.
Shockey, Harry P.
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Simmons, Mary A.
Simonton, Margaret P.
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Singer, Herbert
Sink, James A.
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Sitze, Roy F.
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Slight, John B.
Sloan, James E.
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Smart, James
Smead, Wilbur H.
Smith, Alva E.
Smith, Camilla M.
Smith, Charlotte R.
Smith, Dorothy P.
Smith, Earl
Smith, George B.
Smith, Henry A.
Smith, Leona G.
Smith, Norman F.
Smith, Richard F.
Smith, Robert
Smith, Wilma
Smitt, Joseph
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Snead, Wilbur H.
Snyder, Kenneth
Snyder, Richard G.
Sobel, Donald
Sobik, Joseph M.
Sordi, Joseph J.
Soulant, Matthew R., Jr.
Southers, Raymond C.
Spann, Robert L.
Span, Flo
Sparks, Charles E.
Spearing, Robert E.
Speilman, Natalie J.
Spence, Judith
Spencer, Bobby Theron
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Sprake, Marvyn D.
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Stack, Mary J.
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Standwood, Robert K.
Starkey, Sylvia L.
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Stealy, William T.
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Stelges, William R.
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Stevens, R. Lawrence
Stewart, Frederick F.
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Stewart, Lester A.
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Stodgill, Jo Ann
Stoffel, Bernard L.
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Stokes, James C.
Stokes, Katherine S.
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Stonesifer, John C.
Stotler, Herbert J.
Stout, William H.
Stovall, Margie L.
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Strauss, Eugene J.
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Stubbs, Donald R.
Stullken, Donald Edward
Sturdivant, Vernon R.
Sturtevant, Paul M.
Stutz, Lillian G.
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Sulester, James M.
Sullivan, Leslie J.
Sullivan, Walter B.
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Sumner, Kenneth
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Sutton, Cermon S.
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Sweat, C. Downing, Jr.
Sweet, Floyd J.
Taeger, Paul E.
Tagsdale, Mary G.
Talani, Angelo J.
Talbert, Rexford H.
Tartaglia, Anthony D.
Tatham, Steven W.
Tatum, Emma Jo
Taub, William P.
Taub, Willard M.
Taylor, Dale H.

Taylor, Geneveive B.
Taylor, George D.
Taylor, James A.
Taylor, Lafayette C.
Taylor, Maggie S.
Taylor, Robert E.
Taylor, Virginia E.
Tepoel, Harold Eugene
Terry, James F.
Tessler, Martin
Thiberville, A. J., Jr.
Thibodeau, Joseph R., III
Thiel, Alphonse M.
Thiel, John J.
Thoman, Charles A.
Thomas, Geraldine
Thomas, Guy I.
Thamas, James A.
Thomas, James B.
Thomas, Juanita P.
Thompson, Alicia M.
Thompson, Clifford D.
Thompson, Ira T.
Thompson, Jeannine C.
Thompson, Julius T.
Thompson, Robert F.
Thorsen, Rolf E.
Tilson, Lois A.
Tilson, Paul E., Jr.
Timmons, Eddy
Tindall, Howard W., Jr.
Tindall, William
Tischler, A. O.
Tomberlin, James L.
Toney, Marshal A.
Toppen, Theodore
Toryak, Anna W.
Towey, James M.
Townsend, Quwatha S.
Toy, Harold D.
Trader, Arthur G.
Tredway, Harrison E.
Trombley, Joseph R.
Trovillion, Delores L.
Trueblood, Joseph R.
Trulson, Leroy
Tsitsera, Voula
Tucker, Charles M.
Tudge, Henrietta
Tuntland, Richard D.
Turner, Barbara
Turner, Bernadine E.
Turner, Charles A.
Turner, Connie R.
Turner, Don
Turner, Gordon I.
Turner, Kenneth L.
Turner, Thomas R.
Turnock, Dr. James H., Jr.
Turvy, Roscoe R.
Twigg, John M., Jr.
Tynan, Charles, Jr.
Tzaperas, Nick A.
Ulman, Inez L.
Underwood, Thomas C., Jr.
Underwood, William J.
Uzzell, Bobby R.
Vacca, Gennaro A.
Valdyke, George H.
Vale, Robert E.
Van Bockel, John J.
Van Ness, Cdr., Harper E.
Vandeveer, Doris B.
Varnado, Darol B.
Vaughan, Norma
Vaughn, Norbert B.
Vaughn, Patricia L.
Vaugn, Charles M.
Vavra, Paul H.
Velander, Wallace
Verostko, Charles E.
Vestal, Jim
Vetuski, Sims T.
Vincent, John L.
Vinograd, Sherman
Vitale, William V.
Voas, Robert B.
Vogel, Harle L.
Vogel, Kenneth J.
Vogt, Fred B.
Vohringer, Virginia D.
Volpe, Frank A.
Von Ehrenfried, Manfred H., II
Vonroeder, Robert H.
Voris, Capt., Frank B.
Wagoner, Ralph
Walden, Ann D.
Walder, Aden
Waldron, L.
Walker, Gary L.
Walker, Jefferson H., Jr.
Walker, Louie T.
Walker, Vivian
Wallace, Hugh O.
Waller, Barbara E.
Wallis, Robert J.
Walliser, Sylvan A.
Walsh, Leo F.
Walters, Ernest E.
Walters, Louise H.
Walters, William H., Jr.
Walton, Thomas S.
Walz, Joseph E.
Wanczyk, Eleanore
Waranch, Myer
Ward, George L.
Ward, Welby G.
Warnock, Charles F.
Warnock, James M.
Warren, Carlos S.
Warren, James W.
Warren, Lawrence
Wasel, Robert A.
Waters, John G.
Watkins, Edith N.
Watkins, Julia R.
Watson, Riley A.
Watt, John D.
Watts, George A.
Waugh, Merle G.
Webb, Dalton D.
Webb, James E.
Webster, George I.
Wedding, Michael A.
Weedon, Jack Sanford
Weinberger, Robert A.
Weinert, Robert
Weining, Roger F.
Welhan, Alex
Wells, James L., Jr.
Welly, Charles E.
West, Edward L.
West, Julian
West, Walter M., Jr.
Westbrook, Samuel S., Jr.
Westerlage, Lois R.
Westervelt, Maurice A.
Weston, Kenneth C.
Westphal, Ralph L.
Wetmore, Warren C.
Wetzel, Waunita D.
Whalen, John E.
Whatley, Billy G.
Wheeler, Andrew E.
Wheeler, William P.
Wheelwright, Charles D.
Whisenant, Elmo R.
Whitaker, Paul R., Jr.
Whitbeck, Philip
White, James R.
White, Robert
White, Ted A.
Whitehurst, Herman D.
Whiteman, Lynn R.
Whiteside, Carl A.
Whiting, Donald F.
Whitney, Ernest G.
Wible, Veronica A.
Wiggins, Judy
Wikstrom, Harold
Wiley, Alfred N., Jr.
Wilfert, Donald F.
Wilhelm, John R.
Wilkerson, Alex.
Wilkes, T. Marshall
Wilkinson, Reuben L.
Willadson, Richard D.
Williams, David C.
Williams, Elburta B.
Williams, Foster T., III

Williams, Grady F.
Williams, Jack H.
Williams, John Joseph
Williams, John T.
Williams, Joseph B.
Williams, Lawrence G.
Williams, Paul F.
Williams, Richard
Williams, Rose T.
Williams, Thomas N.
Williams, Walter C.
Williams, Wiley Edward
Willis, William E., Jr.
Wilson, Almeda P.
Wilson, Anne F.
Wilson, B. M.
Wilson, James M.
Wilson, Terry L.
Wilson, William T.
Windler, Milton L.
Winn, Grace
Winnette, Walter M.
Winterhalter, David L., Sr.
Winters, James G., Jr.
Wirhan, Nelson R.
Wirman, Nelson R.
Wise, John P.
Wisniewski, Richard J.
Witherington, Guy N.
Wobig, Orrin A.
Woldorff, Leon
Wolfe, Gayle N.
Wolfer, M. Ernestine
Wolhart, Walter D.
Wolman, Dr. William W.
Womack, William D.
Womick, Otto
Wood, Bruce M.
Wood, H. W.
Wood, Sandra
Wood, Wilfred
Woodling, Carroll H.
Woodman, Ray S.
Woodruff, James W.
Woodsmall, Charline W.
Woodward, Charles F.
Woodyard, Charles E.
Woods, Donald J.
Woods, Gary J.
Woods, Thomas F.
Woodyard, Jean M.
Worf, Dr. Douglas L.
Workman, Bob
Wright, David S.
Wright, William W.
Wrightsman, Harold E.
Yannotta, Lucille N.
Yarbrough, Alvie E.
Yates, Sandra S.
Yenni, Kenneth R.
Yodzis, Charles W.
Yokum, Charles O.
Yorker, Lloyd O.
Youmans, Henry B.
Youmans, Randall E.
Young, Earl B.
Young, Eugene N.
Young, Kenneth A.
Young, Minerva S.
Young, William J.
Yusken, John W.
Zarcaro, John G.
Zavasky, Raymond L.
Zedekar, Raymond G.
Zeigler, Irene B.
Ziegler, Thomas A.
Zelenevitz, Joyce
Zepp, John P.
Zetler, Albert
Zirnfus, Edward R., Jr.
Zita, Myrtle C.

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# APPENDIX F

## MA–9 AIR–GROUND VOICE COMMUNICATIONS

The following is a transcript of the MA–9 flight communications derived from both the spacecraft onboard recordings and the Mercury network station recordings to form a single text. It is, therefore, a complete transcript of the air-to-ground and ground-to-air communications during station passes and inflight comments made by the pilot between stations. A few nonflight-related transmissions and an occasional repetitive word or partial sentence were removed by the astronauts and the editors to improve the clarity. Instances of this type are noted by an asterisk at the beginning of the altered transmission. Where a whole transmission has been deleted because of lack of confirmation or nonflight-relationship, the asterisk appears where the transmission was removed. The text is otherwise verbatim.

The format used for presentation is as follows, from left to right: The first column contains the spacecraft elapsed time (c.e.t.) from lift-off in hours, minutes, and seconds at which each communication was initiated. The second column identifies the communicator and the third column contains the text of the communication. The station in communication with the astronaut is designated at the initiation of communications. When no station contact was made for a complete orbital pass the text is headed with the orbital pass number only.

The c.e.t. was reduced from the recording of the spacecraft-clock commutated time segments on both the onboard tape and the network station tapes. These c.e.t. times are accurate to $\pm 0.8$ second. Timing of a few communications was not obtained because of either weak noisy signals on the network tapes, or the short sampling of onboard commutated time segments resulting from commutator sampling interruptions when the pilot was recording in the vox-record programed mode and paused longer than ½ second. When timing was not obtained for either of these reasons, the first column contains the notation "unreadable" for that communication.

The communicators are identified as follows:

P—Pilot
CC—Spacecraft communicator at the range station
SY—Systems monitor at the range station
F—Flight director at Mercury Control Center
R1—Pilot of primary recovery helicopter
R2—Pilot of backup recovery helicopter
Stony—Blockhouse communicator at launch complex 14
K—Communicator onboard the *USS Kearsarge*

At various times throughout the flight, the pilot or network station communicator would indicate a precise time, event, or action by the use of a significant word, such as "MARK", or "NOW". The transcript editors also selected a few significant words or events for timing. The timing of these words or events was accomplished by the same process as that used to determine the c.e.t. times for column one and is indicated by the time enclosed in brackets followed by the superscript T.

All temperatures are given in ° F; all cabin and suit pressures are in pounds per square inch, absolute (psia); fuel and coolant quantities are expressed in remaining percent of total nominal capacities; retrosequence times are expressed as ground elapsed time (g.e.t.) in hours, minutes, and seconds.

Within the test, a series of dots is used to designate communications or portions of communications which could not be deciphered. A single dash indicates a pause during a communication. Information contained within unmarked parentheses indicates editorial insertions for clarification.

| | | |
|---|---|---|
| | Stony | 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, 0. |
| 00 00 01 | CC | Lift-off. |
| 00 00 02 | P | Roger. I have a lift-off and the clock is operating. |
| 00 00 05 | CC | Roger, clock. |
| 00 00 07 | P | Sigma Seven, Faith Seven on the way. |
| 00 00 14 | P | Standing by to start the backup clock. |
| 00 00 16 | CC | Roger. |
| 00 00 18 | CC | 3, 2, 1, MARK. [00 00 20]$^{T}$ |
| 00 00 23 | P | Roger. And the backup clock is running. |
| 00 00 25 | CC | Roger. You look good here, Gordo. |
| 00 00 27 | P | Roger. Feels good, buddy. |
| 00 00 29 | CC | Good sport. |
| 00 00 31 | P | Thirty seconds, and fuel is go. Oxygen is go. Cabin pressure on the top peg. Altemeter is working. |
| 00 00 38 | CC | Roger. You're looking beautiful. |
| 00 00 48 | P | What an afterburner ! |
| 00 00 51 | CC | That's a beauty, and your clock's are in sync. |
| 00 01 01 | P | One minute and fuel is go. Oxygen is go. Cabin pressure, 10 psi on schedule. All systems go. |
| 00 01 09 | CC | Roger. We have a good go here, and pitch, 50 [degrees]. |
| 00 01 29 | CC | Still looks go. |
| 00 01 30 | P | Roger. One minute 30 seconds. Fuel is go. Oxygen is go. Cabin pressure is 6 psi. |
| 00 01 37 | CC | Roger. Pitch 32 [degrees], looks good. |
| 00 01 41 | P | Roger. The Sun is coming in the window now. |
| 00 01 46 | CC | Roger. Standing by for your BECO. |
| 00 01 50 | P | Roger. |
| 00 01 58 | P | Running pretty smooth now. |
| 00 01 59 | CC | Good show. |
| 00 02 02 | P | Two minutes. Standing by on BECO. |
| 00 02 03 | CC | Roger. Time out good. |
| 00 02 14 | P | Roger. Have BECO. |
| 00 02 15 | CC | Roger. Your BECO. Confirm staging. |
| | | *[Undetermined transmission omitted.] |
| 00 02 22 | P | And you can feel the staging—waiting on tower. |
| 00 02 27 | CC | Very good on BECO time ; SECO should be nominal. |
| 00 02 29 | P | Roger. |
| 00 02 38 | P | And there goes the tower. Does she take off ! |
| 00 02 41 | CC | Roger. Confirm your tower. |
| 00 02 43 | P | Roger. Retrojettison switch to off. |
| 00 02 45 | CC | Retrojettison switch off. |
| 00 02 55 | P | *Okay. Fuel is go ; oxygen is go ; cabin pressure sealed at 5.6 [psi] and holding. |
| 00 03 03 | CC | Roger. Sealed on 5.6 [psi] and holding. Very good. Pitch −4 [degrees]. |
| 00 03 10 | P | Roger. I agree on pitch. |
| 00 03 12 | CC | You look real pretty here. |
| 00 03 14 | P | She felt real pretty. |
| | | *[Nonflight-related transmission omitted.] |
| 00 03 24 | P | All electrical is go. Pressure is go. Oxygen is go. Sigma, Faith Seven is all go. |
| 00 03 34 | CC | We have a full go here for you, Gordo. |
| 00 03 36 | P | Roger. |
| 00 03 38 | CC | This is Sigma Seven down here, buddy. |
| 00 03 40 | P | That's what I said. Sigma, Faith Seven is go. |
| 00 03 44 | CC | Roger, Faith Seven. |
| 00 04 00 | P | Four minutes and fuel is still go. Oxygen go. Pressure holding. All systems look good. |
| 00 04 08 | CC | Roger. Your pitch indication is −4 [degrees] ; we concur. |
| 00 04 11 | P | Roger. |
| 00 04 13 | CC | Trajectory looks real good, Gordo. I'll give you a mark on 0.8 [$V/V_r$]. |
| 00 04 17 | P | Roger. |
| 00 04 32 | P | Four plus 30 [seconds]. All systems still go. |
| 00 04 35 | CC | Roger. We're still go here. Coming up on 0.8 [$V/V_r$]. Stand by. |
| 00 04 38 | P | Roger. |

| | | |
|---|---|---|
| 00 04 40 | CC | We have 0.8 $V/V_r$. |
| 00 04 42 | P | Good deal. |
| 00 04 48 | CC | You have a real sweet trajectory, Gordo. |
| 00 04 50 | P | Excellent. |
| 00 04 58 | CC | Go. |
| 00 04 59 | P | Roger. |
| 00 05 04 | P | Roger. I have SECO, sep cap. Going to aux damp. |
| 00 05 09 | CC | Right in there, baby. |
| 00 05 12 | P | Have sep cap green. SECO. I'm on aux damp. Going fly–by–wire. |
| 00 05 24 | P | Everything is green here. |
| 00 05 30 | CC | Seven, we're right smack dab in the middle of the plot. |
| 00 05 34 | P | Say again. |
| 00 05 35 | CC | Smack dab in the middle of the "go" plot. Beautiful. |
| 00 05 45 | CC | Seven. Your turnaround looks beautiful. |
| 00 05 47 | P | Roger. She's yawing around very nicely. What a view. Boy, oh boy! |
| 00 05 59 | P | And there's the booster. |
| 00 06 03 | CC | Real pretty. |
| 00 06 04 | P | Boy, oh boy, is it ever close, too. |
| 00 06 08 | CC | Fun, isn't it? |
| 00 06 10 | P | Yeah. |
| 00 06 18 | P | Fly–by–wire is working just like advertised. |
| 00 06 21 | CC | *We have good indications on systems here. You did a real good job of it. |
| 00 06 44 | P | Booster is still smoking. It looks silver, Wally. |
| 00 06 48 | CC | Good. |
| 00 07 06 | CC | Hello. Cape Cap Com. |
| 00 07 17 | CC | Faith Seven, Cape Cap Com. Seven, Cape Cap Com. |
| 00 07 19 | P | I'm in retroattitude or in orbit attitude. |
| 00 07 23 | CC | Faith Seven, Cape Cap Com. How do you read? |
| 00 07 25 | P | Roger, Cape Cap Com. Faith Seven reading you loud and clear. |
| 00 07 29 | CC | Roger. You're on Bermuda relay, and you're coming in real sweet, and everything looks perfect here. |
| 00 07 33 | P | Roger. Looks mighty good here. Booster is really in sight. |
| 00 07 37 | CC | Very good. What color is she? |
| 00 07 39 | P | *Silver. Silvery as can be with a white frosty band right around the middle. |
| 00 07 45 | CC | Roger. Understand. |
| 00 07 53 | CC | Faith Seven, this is Cape. Your 1–Alpha [contingency recovery area retrosequence] time is nominal. |
| 00 07 57 | P | Roger. Thank you. |
| 00 08 05 | P | Yaw shows up very well. |
| 00 08 07 | CC | Roger. Are you ready to copy [recovery area] 2–1 [retrosequence] time? |
| 00 08 10 | P | Negative. Stand by and let me get on auto here. |
| 00 08 35 | P | Going to auto control. |
| 00 08 37 | CC | Roger. How is she hitting in auto? |
| 00 08 39 | P | Roger. No quiver at all on the rates. I'm in auto. She seems to be holding so far. |
| 00 08 45 | CC | Very good. Let me know when you're ready for 2–1. |
| 00 08 48 | P | Roger. |
| 00 08 51 | CC | Pretty nice equipment, isn't it? |
| 00 08 54 | P | Very nice. |
| 00 09 00 | CC | Faith Seven, Cape. We had a cabin [heat exchanger] dome [temperature] of 65 [degrees] at Bermuda. |
| 00 09 08 | P | Roger. I have a cabin dome of 65 [degrees] and a suit dome of about 64 [degrees]. |
| 00 09 13 | CC | Roger. |
| 00 09 15 | P | I'm increasing flow very slightly. |
| 00 09 17 | CC | Roger. You're increasing flow slightly. |
| 00 09 23 | CC | I'll give you your 2–1 [recovery area retrosequence] time, and you can write it later. It's 01+27+52. Over. |
| 00 09 31 | P | Roger. 01 27 52. |
| 00 09 34 | CC | Roger. And [contingency recovery area] 1–Alpha [retrosequence time] is nominal. Have a good ride, boy. |
| 00 09 38 | P | Thank you, buddy. |

| | | |
|---|---|---|
| 00 10 26 | P | Roger. My $T_s$+314.5 lights have gone out. Squib switch to off.<br>[A dome-temperature warning tone occurs at 00 11 00]T |
| 00 12 43 | P | And the booster is still following me along at 12 minutes 45 seconds. It's coming down into the bottom of the window. ASCS is working nicely. It is diverging [drifting] off, to the 11 degrees. . . . |
| 00 13 06 | P | *Seems to be correcting properly. I have both suit and cabin dome temps on bottom peg. I'm going back to my initial setting. *[Nonflight-related transmission omitted.] |

CANARY ISLANDS (FIRST PASS)

| | | |
|---|---|---|
| 00 14 53 | CC | Faith Seven. Faith Seven, this is Canary Cap Com. We have T/M solid. We would like a temperature readout, our segment is very low. That's dome temperature, Faith Seven, suit dome. |
| 00 15 07 | P | Roger, Canary Cap Com. Faith Seven reading you loud and clear. What temperatures would you like? Over. |
| 00 15 14 | CC | I would like a readout of suit [heat exchanger] dome temperature. Over. |
| 00 15 19 | P | Roger. My suit dome temp warning light is on. I have gone back to my initial suit setting. My cabin dome was on, and I have gone back to my initial setting on it. Cabin dome temperature is normal, about 52 degrees. Suit dome is still setting down rather low. I think it is coming back up though. Over. |
| 00 15 45 | CC | *Roger. Understand. I have a message from the Cape. [Contingency recovery] area 1–Bravo [retrosequence time] is nominal. Your apogee is 144.6 [nautical miles]. You will have no problems with nighttime. Also the Cape would like a blood pressure at this time. They missed it at Bermuda. Over. |
| 00 16 08 | P | Roger. Sending you blood pressure now. |
| 00 18 31 | P | Canary Cap Com. |
| 00 18 35 | CC | This is Canary Cap Com. Have you started your $T^s$+5 second check? Over. |
| 00 18 39 | P | I'm getting ready to start it right now. |
| 00 18 43 | CC | Roger. |
| 00 19 47 | CC | This is Canary Cap Com. Would you confirm your 16-millimeter camera is off? Over. |
| 00 19 56 | P | Roger. 16-millimeter camera is off. |
| 00 19 58 | CC | Roger. |
| 00 21 12 | CC | This is Canary Cap Com. Could you give us another readout on suit dome temp. We have lost T/M on that segment. Over. |
| 00 21 20 | P | Roger. Suit dome temp is slowly coming up here. It's still reading about 40 [degrees], but it's easing back up now. |
| 00 21 31 | CC | Roger. |
| 00 21 35 | CC | We are having T/M LOS. Could you give us a reading on cabin dome. It's going back down at LOS here. |
| 00 21 44 | P | Roger. At 50 [degrees], cabin dome. |
| 00 21 53 | CC | Faith Seven, this is Canary Cap Com. Do you read? Over. |
| 00 21 58 | P | Roger, Canary, Faith Seven. Still reading you. |
| 00 22 11 | CC | Faith Seven, this is Canary Cap Com. Do you read? Over. |

KANO (FIRST PASS)

| | | |
|---|---|---|
| 00 22 16 | CC | Faith Seven, this is Kano Cap Com. We have T/M solid. We request the suit-dome temperature reading. We have no reading on the ground. Over. |
| 00 22 28 | P | Roger, Kano Cap Com. I have about 42 degrees. The suit-dome temp is easing back up now. Over. |
| 00 22 36 | CC | Roger. You are 42 degrees. |
| 00 22 39 | P | That is affirm. |
| 00 22 44 | CC | Kano, Roger. |
| 00 22 49 | CC | Faith Seven., this is Kano Cap Com. We have an indication that your TV is still on. Will you confirm? Over. |
| 00 22 58 | P | TV is off now. |
| 00 23 01 | CC | Kano, Roger. |
| 00 23 09 | P | Thank you. |
| 00 23 13 | CC | We request a cabin-dome temperature reading. Over. |
| 00 23 21 | P | Roger. Cabin-dome temp is bouncing around a little. It now reads 42 [degrees]. I've decreased my setting here slightly on it. |
| 00 23 35 | CC | Kano, Roger. We're reading 40 [degrees] on the ground. |

| | | |
|---|---|---|
| 00 26 46 | CC | Faith Seven. Give us another cabin-dome temperature, please. |
| 00 26 50 | P | Roger. Cabin-dome temperature is 54 degrees. |
| 00 26 57 | CC | Please give us suit dome. |
| 00 26 58 | P | Roger. Suit dome is 40 [degrees]. I have decreased my setting a little more to ease it on up. Over. |
| 00 27 07 | CC | *Thank you. What is your present setting? |
| 00 27 10 | P | Roger. I am down below my nominal setting now. |
| 00 27 13 | CC | Roger. |
| 00 27 43 | CC | Faith Seven. We had a roll scanner ignore. Are you orienting the capsule at all? Over. |
| 00 27 49 | P | Negative. |
| 00 27 51 | CC | Roger. |

ZANZIBAR (FIRST PASS)

| | | |
|---|---|---|
| 00 30 47 | CC | Faith Seven, Faith Seven, this is Zanzibar Cap Com. How do you read? |
| 00 30 54 | P | Roger, Zanzibar. Reading you loud and clear. Faith Seven here. |
| 00 30 57 | CC | Faith Seven. Our telemetry on the ground looks like you have a very good capsule at this time. We would like to confirm the suit-dome temperature, however. |
| 00 31 07 | P | Roger. The suit-dome temperature is still down low. I'm easing up on it. |
| 00 31 12 | CC | We're reading approximately 40 degrees on the ground. |
| 00 31 15 | P | Roger. I'm indicating about 42 [degrees] here, and I have decreased my setting. It should be coming up momentarily. |
| 00 31 27 | CC | Could you give me auto fuel, manual fuel, and oxygen readings? |
| 00 31 32 | P | Roger. Auto is still 101 [percent]. Manual is 102 [percent]. Oxygen is 196 [percent] on primary and 100 [percent] on secondary. |
| 00 31 44 | CC | Roger. |
| 00 32 20 | CC | Faith Seven, Zanzibar Cap Com. |
| 00 32 24 | P | Go ahead, Zanzibar. |
| 00 32 25 | CC | *We just had a report from the Cape. Based on Smithsonian 2, you have approximately 20 over 25 orbits. This gives you approximately three times as much on more conservative estimates. |
| 00 32 45 | P | Roger. I understand I have at least 25 then. Is that affirm? |
| 00 32 51 | CC | Faith Seven. Zanzibar Cap Com. |
| 00 32 55 | P | Go ahead, Zanzibar. Faith Seven. |
| 00 32 58 | CC | Have you confirmed your $T_S$+5 check and that the TV is off? |
| 00 33 03 | P | That is affirm. TV is off. I have confirmed my $T_S$+5 second check. |
| 00 33 10 | CC | Roger. |
| 00 33 26 | CC | Faith Seven, Zanzibar Cap Com. |
| 00 33 28 | P | Go ahead Zanzibar, Faith Seven. |
| 00 33 31 | CC | We've had a slight rise on both cabin and suit-dome temperature. |
| 00 33 39 | P | Roger. I have a cabin [heat exchanger] dome [temperature] up to 60 [degrees]. Suit [heat exchanger] dome is still about 42 [degrees]. Over. |
| 00 33 45 | CC | Cabin-dome 60 [degrees]. Suit-dome temp, 42 [degrees]. |
| 00 33 48 | P | That's affirm. |
| 00 33 51 | CC | Roger. You received that [contingency recovery area] 1–B [retrosequence time] was nominal. Is that correct? |
| 00 33 52 | P | Roger. Understand it is nominal. |
| 00 33 56 | CC | Okay, do you have anything else for this time for us? |
| 00 34 02 | P | Negative. Not this trip, I don't believe. |
| 00 34 05 | CC | Please repeat. |
| 00 34 07 | P | Negative. Not this time. |
| 00 34 09 | CC | Roger. We'll leave you alone then. |
| 00 34 11 | P | Roger. Thank you. |
| 00 36 46 | CC | Zanzibar Cap Com. Do you read? |
| 00 36 48 | P | Roger. |
| 00 36 50 | CC | Negative. We had a small problem on T/M on the ground. What is your ASCS bus reading? |
| 00 36 59 | P | ASCS bus reading, 121 [volts]. |
| 00 37 02 | CC | We confirm. We had a small T/M problem. |
| 00 37 05 | P | Roger. |
| 00 37 06 | CC | Zanzibar, out. |
| 00 37 30 | CC | Faith Seven, Zanzibar Cap Com. How about giving me a suit and dome right now? It'll be LOS time. |

| | | |
|---|---|---|
| 00 37 36 | P | Roger. Suit dome is about 45 degrees. Cabin dome is about 61 degrees. |
| 00 37 43 | CC | Roger. Thank you very much. See you next time. |
| 00 37 46 | P | Roger. Will do. |
| 00 38 35 | P | Okay. I finally have my dome temps—fairly good handle on them. I have about 62 [degrees] on the cabin dome. I have approximately 45 [degrees] on the suit dome. These temperatures have taken a setting of 2.0 [comfort-control-valve setting] on the suit and about 3.8 [comfort control valve setting] on the cabin. I have checked my control systems out. Manual proportional is operational. It is very sloppy compared to fly-by-wire low. The Sun is very hot coming in the window. I have the Sun directly in the window. I have from fairly midway through the launch. Lost it at the top of the trajectory. And then picked it up again when I yawed back around to orbit attitude. |
| 00 39 50 | P | My cabin pressure has slowly dropped to the advertised value of 5.2 [psia] and appears to be holding. My suit dome has dropped down again now to about 42 [degrees] and seems to be oscillating about this point area. Body temperature is good, not quite as cool as I would prefer, but good. My suit inlet temperature indicates 60 degrees, however, so the sun is probably the biggest factor heating me up. I have drunk some water. |
| 00 40 56 | P | Time for my short status report. My $N_2$ low pressures, auto is 475 [psi]; manual is about 480 [psi]. B-nut temperatures: retro temp, 60 degrees; pitch down, 85 [degrees]; pitch up, 84 [degrees]; yaw left, 78 [degrees]; yaw right, 89 [degrees]; roll counterclockwise, 90 [degrees]; roll clockwise, 90 [degrees]. |
| 00 41 57 | P | Peroxide reserve tank temperature, 68 [degrees]; peroxide manual tank temp, 69 [degrees]; peroxide auto fuel tank temp is 72 [degrees]. |
| 00 42 30 | P | Isolated bus voltage is 28 [volts]. |
| 00 43 22 | P | *First night side and I have a bright blue band. A thick diffused band of blue color. A bright blue band. The Sun is spread out very widely. It's setting now. And there it goes. A very bright blue band all the way around the earth. |
| 00 44 03 | P | Captured another washer. That's my second one. |
| 00 45 16 | P | *I believe I have the dome temps somewhat under control now. My face plate is open. Cabin air is indicating 100 degrees. Suit inlet temp is 60 degrees. Dome temperature has stabilized pretty well. There is a very pronounced band—a bright blue band—around the Earth. ASCS is holding attitude very well on this night side. |
| | | *[Non-flight-related transmission omitted.] |
| 00 47 14 | P | Taking my pilot light out, NOW [00 47 15]$^{T}$—very good. |
| 00 47 43 | P | Turning my warning lights off—to dim. |
| 00 47 58 | P | And I have the haze layer that Wally was talking about. I can see the stars down in it. But it is—up and around the Earth—to a number of degrees. It is several degrees thick, perhaps 12 to 15 degrees thick. I can see the stars above it, I can see the stars down in it. |
| 00 48 35 | P | *I have seen several lightning flashes on the Earth, now. I see them on the Earth, now. |
| 00 49 19 | P | *Water squeezers are working. |
| 00 49 53 | P | Closing my face plate. |
| 00 50 05 | P | And there is Orion, Betelgeuse. What a beautiful night tonight. |

MUCHEA (FIRST PASS)

| | | |
|---|---|---|
| 00 51 02 | CC | Faith Seven, Faith Seven, Muchea Cap Com. Over. |
| 00 51 06 | P | Roger, Muchea Cap Com, Faith Seven. |
| 00 51 10 | CC | Roger. Reading you loud and clear. |
| 00 51 11 | P | Roger. Likewise here. How are things down there? |
| 00 51 12 | CC | Very fine, very fine. |
| 00 51 16 | P | Roger. |
| 00 51 21 | P | You appear to be having a little lightning and thunderstorms down there. |
| 00 51 26 | CC | Looks clear from here. |
| 00 51 29 | P | Roger. Back out to the west of you there are some. |
| 00 51 33 | CC | Aeromed is standing by for your blood pressure. |
| 00 51 41 | P | Roger. Blood pressure coming now. |
| 00 52 01 | CC | Faith Seven. How does your cabin dome and suit dome temp look now? |
| 00 52 17 | P | Roger. I was waiting until the blood pressure got finished there. |
| 00 52 25 | CC | How does your suit and cabin [heat exchanger] dome [temperature] look now? |
| 00 52 26 | P | *Roger. My cabin dome and suit dome [temperatures] have been fluctuating somewhat. |

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|---|---|---|
| 00 52 36 | CC | Stand by for emergency voice check. |
| 00 52 38 | P | Roger. |
| 00 52 45 | CC | This is Muchea Cap Com, transmitting on emergency voice for a short count. 1, 2, 3, 4, 5, 5, 4, 3, 2, 1. Do you copy? |
| 00 52 58 | P | Roger, Muchea Cap Com. Reading you loud and clear on emergency voice. |
| 00 53 02 | CC | Roger. |
| 00 53 07 | P | Roger. On these dome temps, I have decreased my setting again, and my cabin dome is running about 48 degrees. My suit dome is back on the bottom, 40 degrees now. I've decreased it; it should be coming back up momentarily. |
| 00 53 25 | CC | Roger. Stand by for an astro alarm check. |
| 00 53 31 | P | Roger. |
| 00 53 34 | CC | Command is on the way. [Command tone occurs at 00 53 35] [T] |
| 00 53 36 | P | Roger. I have retro reset light and the tone. |
| 00 53 40 | CC | Roger. |
| 00 53 56 | CC | *Faith Seven, would you give me a reading on your cabin temperature please.* |
| 00 54 00 | P | Roger. Cabin temperature is running 100 degrees. |
| 00 54 04 | CC | Roger. |
| 00 54 12 | CC | Faith Seven. Perth has their lights on tonight; you might look for them and see if they're visible. |
| 00 54 19 | P | Roger. |
| 00 54 21 | CC | They should be just slightly off to the right of your flight path. |
| 00 54 27 | P | Roger. I'll watch for them. |
| 00 54 28 | CC | Roger. |
| 00 55 03 | P | Roger. I have the lights of Perth in sight. Loud and clear. |
| 00 55 08 | CC | Roger, Faith Seven. People here will be glad to hear that. |
| 00 55 11 | P | Roger. Looks good. |
| 00 55 23 | P | Looks like the refinery down to the south is burning again too. |
| 00 55 27 | CC | *That's affirmative. |
| 00 55 29 | P | Roger. I can see that separately. |
| 00 55 32 | CC | Cape Flight would like to know how your ASCS is working now after selecting gyro slave. |
| 00 55 37 | P | Roger. ASCS appears to be operating as advertised. Over. |
| 00 55 42 | CC | Roger. |
| 00 55 52 | CC | This is Muchea Cap Com. We have about 1 minute to LOS. |
| 00 55 56 | P | Roger. |
| 00 56 47 | CC | *Faith Seven, Muchea Cap Com. Could you give us your [comfort] control valve setting?* |
| 00 56 57 | P | Roger. I'll give you my heat exchanger dome temps here. |
| 00 57 00 | CC | Roger. |
| 00 57 03 | P | Roger. I'm reading 52 degrees on cabin dome, and I'm reading 40 degrees on suit. I have decreased suit again, slightly. And it should be coming up again. |
| 00 57 15 | CC | Roger. |
| 00 58 45 | P | *This haze layer. I'm describing as light in color. It's a white haze, does not appear to have any color at all to it. |
| 01 04 08 | P | I now have the suit coolant valve set to 1.5, cabin valve set to launch mark, about 3.6, and cabin [dome temperature] reads 50 degrees, and suit [dome temperature] is coming up slowly, now reads about 45 degrees. Suit inlet temp is about 58 degrees. |
| 01 05 18 | P | There is considerable cloud cover over the Earth now. This haze layer is still up above that. I can see a dark hazy sky above the Earth, and then this haze layer appears to be sitting several degrees—it's hard to estimate the number of degrees—above the Earth. The stars are in the background. The stars are above this haze layer, and they're quite clear, of course, above it. |
| 01 06 07 | P | Long status report. B-nut temperature: Pitch down is 90 [degrees]; pitch up is 85 [degrees]; Yaw left is 82 [degrees]; yaw right is 95 [degrees]; roll counterclockwise is 92 [degrees]; roll clockwise is 92 [degrees]. Cabin outlet, 40 degrees; 250 inverter, 110 degrees; 150 inverter, 112 degrees; standby inverter, 90 (degrees). Cabin temperature, 102 degrees; suit temp 58 degrees. Heat exchanger dome temps: cabin is now 50 [degrees]; suit is now 46 [degrees]. |
| 01 08 04 | P | I'm reading 18 amps on current. Main bus reads 24 [volts]; isolated [bus], 28 [volts]; number one battery, 24 [volts]; number two battery, 24 [volts]; number three battery, 24 [volts]; standby [battery] one, 25 [volts]; standby [battery] two, 25 [volts]; isolated [battery], 28 [volts]. |
| 01 08 36 | P | I'm now opening my face plate to take an oral temp. |

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|---|---|---|
| 01 10 02 | CC | Faith Seven, this is Canton Cap Com. Over. |
| 01 10 14 | CC | Faith Seven, we have a valid body temp. |
| 01 10 18 | P | Roger, I'll talk to you then. Ha, ha ! Faith Seven here, reading you loud and clear. |
| 01 10 24 | CC | Roger. Would you give me a readout on your cabin heat exchanger dome temp, please. |
| 01 10 31 | P | *Roger, standby 1 second. Roger. Cabin heat exchanger dome temperature is 50 degrees; suit heat exchanger dome temp is 45 degrees; the suit inlet temperature is 58 degrees; and cabin outlet temperature is about 40 degrees. |
| 01 11 03 | CC | Understand, 43. |
| 01 11 05 | P | 40. |
| 01 11 07 | CC | 40. |
| 01 11 35 | CC | Seven, Canton. |
| 01 11 37 | P | Go ahead Canton, Faith Seven. |
| 01 11 41 | CC | [Recovery] area 2–1 retrosequence time 14 32 03. Over. |
| 01 11 49 | P | 14 32 03. Roger. |
| 01 11 52 | CC | Affirmative. |
| 01 11 54 | P | Roger. |
| 01 12 25 | CC | Seven, Canton. Your c.e.t. [capsule elapsed] time on the 2–1 retrosequence time is 01 27 50. Over. |
| 01 12 39 | P | Roger. 01 27 50. That's on 2–1. Is that affirm? |
| 01 12 45 | CC | Affirmative. |
| 01 12 47 | P | Roger. |
| 01 13 02 | CC | *Seven, Canton. All readouts are in the green. |
| 01 13 06 | P | Roger, they all look green here, thank you. |
| 01 18 01 | P | *I have transferred the urine from the internal suit bag to the number one bag at this time. |
| 01 19 27 | P | Alpha and Beta Centauri. |
| | | *[Non-flight-related transmission omitted.] |
| 01 20 52 | P | Sweet little baby. |
| 01 21 15 | P | *At this time I now have 1 hour and 21 minutes and I am observing John's fireflies drifting away from me. I can observe them—appear to be departing from the spacecraft and drifting out to the rear. I then can see some of them a considerable distance out to the rear. |
| 01 22 02 | P | The Sun is coming up behind me; I'm beginning to get the glow on the clouds. |
| 01 22 22 | P | *The fireflies appear to be white, very whitish, almost a green, like real fireflies. |
| 01 23 01 | P | The clouds on the Earth below are changing color, are getting quite light. |
| 01 23 54 | P | *I am now on the day side; the Sun is not yet quite up and I am observing stars. The Earth is light below me. The sun is still behind me, the sky looks dark above me, and I can see stars very distinctly. |
| 01 24 41 | P | I am decreasing cabin dome [comfort control valve setting] now to about 3.4. |

GUAYMAS (FIRST PASS)

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|---|---|---|
| 01 27 13 | CC | Faith Seven, Guaymas Cap Com. |
| 01 27 16 | P | Roger, Guaymas Cap Com, Faith Seven here. |
| 01 27 19 | CC | Hey, Gordo, give me your heat exchanger outlet temperatures please. |
| 01 27 24 | P | Roger. I've got 50 [degrees] on the cabin, and 50 [degrees] on the suit. |
| 01 27 31 | CC | Roger. Are you comfortable? |
| 01 27 34 | P | Roger. Just slightly warmer than absolutely ideal, but well within a very comfortable range. My suit inlet temperature is 58 degrees. Over. |
| 01 27 43 | CC | Very good. Everything looks good down here. We give you a go for seven more. |
| 01 27 48 | CC | We are giving you a go for seven orbits. |
| 01 27 51 | P | Roger, for 30 how many? |
| 01 27 55 | CC | As many as you want. |
| 01 27 56 | P | Ha, ha ! Roger. |
| 01 27 58 | CC | And Gemini sends you their regards. |
| 01 28 03 | P | Roger. Thank you. |
| 01 28 08 | CC | Will you give me a short report? |
| 01 28 12 | P | Roger. It's great. |
| 01 28 19 | CC | That's good enough. |
| 01 28 22 | P | It's pretty hard to describe, but it really is. I've seen the haze layer that Wally talked about, and I've seen John's fireflies, saw the lights of Perth, and it's been quite a full night. Quite impressive. Everything appears very nominal on board here. |

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| 01 28 40 | CC | How was the sunrise? |
| 01 28 42 | P | Quite impressive. |
| 01 28 49 | P | Everything seems very nominal on board here. |
| 01 28 53 | CC | Excellent. |
| 01 29 11 | P | How's the fishing? |

CAPE CANAVERAL (SECOND PASS)

| | | |
|---|---|---|
| 01 33 50 | CC | Faith Seven, Cape Cap Com. |
| 01 33 52 | P | Roger, Cape Cap Com. Faith Seven here. |
| 01 33 55 | CC | Roger. You look real good. I'm going to send you a T/M command. |
| 01 33 59 | P | Roger. |
| 01 34 05 | CC | I will wait for your TV camera. |
| 01 34 08 | P | Roger. |
| 01 34 14 | CC | Gordo, could you give me a readout on your $H_2O_2$ pressures, please? |
| 01 34 20 | P | Pressure? |
| 01 34 22 | CC | Pressure. |
| 01 34 23 | P | I have 475 [psi] auto and I have 490 [psi] in manual. |
| 01 34 29 | CC | Roger. You're getting kind of chinchy on this fuel up there. |
| 01 34 32 | P | Roger. FQI [fuel quantity indicator]: I'm indicating 101 [percent] on auto and 102 [percent] on manual. |
| 01 34 41 | CC | You son-of-a-gun, I haven't got anything to talk about. |
| 01 34 42 | P | Ha, ha, ha! |
| 01 34 46 | CC | How's your $H_2O$ separator lights working? |
| 01 34 51 | P | Fine. They're just beating their little hearts out every 10 minutes. |
| 01 35 00 | Stony | Faith Seven, this is Stony. Maybe, maybe the FQI is stuck. Why don't you try the hammer? |
| 01 35 07 | P | Ha, Ha! I'll save that for later. I'm thinking of using the hammer on the dome temp, however. On the dome temp light. |
| 01 35 20 | CC | We're starting to pick a picture up now. You look pretty casual. |
| 01 35 27 | P | Oh, I am. |
| 01 35 41 | CC | Do you want to do your KK experiment over us please? |
| 01 35 45 | P | Roger. Opening the KK clamp. |
| 01 35 52 | CC | Roger. |
| 01 36 42 | P | Roger. I'm getting ready to power down. |
| 01 36 46 | CC | Roger. I would like to have you open up your TV about one stop. |
| 01 36 51 | P | Roger. Is that any better? It's already wide open. |
| 01 37 08 | CC | Roger. I still see that fly on your nose. |
| 01 37 13 | P | Ha, ha, ha! |
| 01 37 17 | CC | Okay, Gordo. I guess you can shut your power down. |
| 01 37 19 | P | Roger. Going to fly-by-wire low. On fly-by-wire low. |
| 01 37 22 | CC | Roger. |
| 01 37 30 | P | Going to fly-by-wire low. Going to gyros caged, and they caged just as advertised. And ASCS a–c bus off. |
| 01 37 50 | CC | Roger. Checking volts down, and amps down. |
| 01 37 54 | P | Roger. |
| 01 38 28 | P | *Apparently the heat exchanger dome temps have stabilized pretty well now. |
| 01 38 36 | CC | Roger. It takes quite a while to get a grasp on it. |
| 01 38 38 | P | Roger. |
| 01 38 43 | CC | Before LOS, don't forget your TV camera. We're still reading you very well now. |
| 01 38 50 | P | Roger. |
| 01 39 01 | CC | The other item to check is your tape recorder on program. |
| 01 39 05 | P | Roger. Tape recorder going to program. |
| 01 39 08 | CC | You are program. |
| 01 39 10 | P | Are you still receiving the TV picture? |
| 01 39 13 | CC | That's affirm. |
| 01 39 19 | P | Roger. I'll hold. Turning it off for a moment. |
| 01 39 21 | CC | Okay. |
| 01 39 30 | P | Mode select switches to off. |
| 01 39 33 | CC | Roger. Mode, off. |
| 01 39 35 | P | Manual fuel is off. |

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|---|---|---|
| 01 39 38 | CC | Manual, off. |
| 01 39 44 | CC | Frank [Samonski] says you can stop holding your breath any time and use some oxygen if you'd like. |
| 01 39 49 | P | Okay. You set such a good example; I've got to equal you here. |
| 01 40 01 | CC | Yeah, you son-of-a-gun. I'm still higher and faster, but I have an idea you're gonna go farther. |
| 01 40 09 | P | Al, what is my apogee height? |
| 01 40 15 | CC | It's about 146 nautical [miles]. |
| 01 40 19 | P | Roger. |
| 01 40 20 | CC | You can kill your TV, Gordo. |
| 01 40 22 | P | Roger. TV off. |
| 01 40 24 | CC | Roger. And put your C-band to ground command. |
| 01 40 31 | P | Roger. C-band's on ground command. S-band's on ground command. |
| 01 40 37 | CC | Roger. |
| 01 40 40 | P | Recorder on program; I'm leaving telemetry on continuous. |
| 01 40 50 | CC | All of our monitors down here are overjoyed. Everything looks beautiful. |
| 01 40 54 | P | Very good. Looks mighty good up here, too. |
| 01 41 02 | CC | There's LOS on your T/M. Bermuda may have picked up, but I don't think they'll discover anything we haven't. |
| 01 41 09 | P | Roger. |
| 01 41 43 | CC | Faith Seven. This is Sigma Seven. Do you read? |
| 01 41 46 | P | Roger. Sigma Seven, Faith Seven reading you loud and clear. |
| 01 41 49 | CC | Roger. We have no messages for you. We'll let you have some quiet time. Have a good ball. |
| 01 41 54 | P | Roger. Thank you. |
| 01 42 03 | P | Might tell Bob Graham I've found a couple of those items that we were discussing. I can see the smudge layer on the window that Wally was discussing. It looks just like road grease splashed on a car. It also has spreckledy, streakedy, dots on it, smudged in with it. The smudge—the added smudges—run length of the window. Closing my visor now at 01 44 38. |

CANARY ISLANDS (SECOND PASS)

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|---|---|---|
| 01 48 26 | CC | Faith Seven, this is Canary Cap Com. We have T/M solid, all systems look green. Over. |
| 01 48 35 | P | Roger, Canary Cap Com. I'm turning TV on here for you. |
| 01 48 41 | CC | Roger. |
| 01 48 45 | P | All systems are green here. |
| 01 48 48 | CC | Roger. Your [contingency recovery area] 2–Bravo [retrosequence] time is nominal. |
| 01 48 52 | P | Roger. Nominal, thank you. |
| 01 50 19 | CC | Faith Seven, this is Canary Cap Com. We're having T/M LOS. Turn off your TV. Over. |
| 01 50 26 | P | Tv control to off. |
| 01 50 28 | CC | Roger. |
| 01 50 38 | P | Drifting now; I was upside down in roll attitude. Just passed over Canaries. Everything appears nominal. |
| 01 51 09 | P | I'm now receiving a Z and R cal apparently from program. |
| 01 52 22 | P | *Coming in over the coast of Africa. It's very clear here: no clouds, no haze. I'm drifting through an ideal location here. I'll try and snap off the 16 millimeter. Just took a 16-millimeter blurb coming over the Atlas Mountains in Africa. Coming over the coast. It's very dry, very clear over Africa. I'm drifting window down, ideal attitude. I'm now increasing my suit flow by just a hair. I'm opening my visor now. Cabin still appears drier than the suit. Apparently suit is running a little moist, although it doesn't feel it at all. Had six or seven large sips of water from the drinking-water container. I have put a little liquid into this little experimental ball and find that the liquid adheres to the surface just near as good as it should. Try a little bit more later on here. |

## KANO (SECOND PASS)

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|---|---|---|
| 01 55 02 | CC | Kano, has solid T/M. |
| 01 55 09 | P | Roger, Kano, Faith Seven. Everything's nominal here. |
| 01 55 14 | CC | Faith Seven, this is Kano Cap Com. Everything looks nominal on the ground. Have a good trip. |
| 01 55 19 | P | Roger. Thank you very much. |
| 02 00 36 | P | *At 2 hours, recording light is on; so I'll slip something on the tape. All systems appear nominal. My . . . cabin dome temp is 48 degrees; suit dome temp is about 56 degrees. Oxygen is still on the top peg on both systems. So is the fuel. Cabin temp, 98 [degrees]. . . . 2 hours and 3 minutes . . . 2 hours and 4 minutes. MARK [Unreadable].[T] Rate indicators are on, I am drifting at this point; I have left roll rate of about half a degree/sec. I have a pitch down rate of about one-quarter of a degree/sec and a right yaw rate of about one-half of a degree, and relatively constant. They're all considerably different than nominal. I don't feel that it's worth going into all the settings. I think the cabin dome temp is the important thing. |

## ZANZIBAR (SECOND PASS)

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|---|---|---|
| 02 05 20 | CC | Faith Seven, Zanzibar Cap Com. |
| 02 05 23 | P | Roger, Zanzibar. Faith Seven reading you loud and clear. |
| 02 05 26 | CC | Reading you loud and clear, also. I have your [contingency recovery area] 2–B [retrosequence] time. It is nominal. Do you need it? |
| 02 05 34 | P | Negative, I have it. Understand nominal. |
| 02 05 37 | CC | That is affirmative. Would you give me a readout of your cabin heat-exchanger dome temperature? |
| 02 05 45 | P | Roger. It is sitting on 40 [degrees]. It has just gone down here; it's bobbing around, and I am decreasing my flow to it. |
| 02 05 54 | CC | Roger. |
| 02 06 02 | CC | Can you give me fuel and oxygen readouts, please? |
| 02 06 06 | P | Roger. I am still indicating 101 percent on auto, 102 percent on manual. I'm reading 196 percent on primary oxygen, and 100 percent on secondary. Over. |
| 02 06 22 | CC | Roger. |
| 02 06 28 | CC | How do you feel about this heat situation? |
| 02 06 34 | P | What, the heat exchanger? |
| 02 06 35 | CC | No, how is your comfort? |
| 02 06 38 | P | Roger. My comfort is good. |
| 02 06 43 | CC | Your comfort is good. |
| 02 06 44 | P | That's affirmative. |
| 02 06 54 | P | My cabin heat exchanger [dome temperature] is easing back up now to about 42 [degrees]. Slowly coming back up. |
| 02 07 00 | CC | Roger. |
| 02 07 02 | P | I have about 42 [degrees], and it's coming back up slowly now. |
| 02 07 05 | CC | Roger. |
| 02 07 07 | P | . . . dome temp. |
| 02 07 08 | CC | T/M confirms all your systems go. Your clock is in sync. |
| 02 07 14 | P | Roger. |
| 02 07 23 | CC | T/M indicates you are getting a rise in your cabin [heat exchanger] dome temperature, also. |
| 02 07 29 | P | Roger. |
| 02 09 12 | CC | Faith Seven, Zanzibar Cap Com. |
| 02 09 14 | P | Roger, Zanzibar. Go ahead. |
| 02 09 16 | CC | We've had another increase in cabin heat exchanger dome temperature. It's now 48 degrees on the ground. |
| 02 09 23 | P | Roger. I agree. |
| 02 09 25 | CC | Roger. |
| 02 09 32 | CC | What is your dome setting—the handle setting at the present time? |
| 02 09 42 | P | Nominal. I don't feel that it's worth going into all the settings. I think the dome—the cabin [heat exchanger] dome temps are the important things. |
| 02 09 49 | CC | Roger. You're getting weak and fading. I'll sign off and see you later. |
| 02 09 53 | P | Roger. |

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| 02 14 12 | P | The time is 02 14 15. People wonder if it's hard to sleep up here. I just drifted off for about 3 or 4 minutes on a quick little nap. Sleep here just like you do anywhere else. Status report. Nitrogen low pressure; auto source, 494 [psi]; manual 490 [psi]. FQI [fuel quantity indicator]; 101 [percent] on auto; 102 [percent] on manual. [B-nut] temps: pitch-down, 95 [degrees]; pitch-up, 85 [degrees]; yaw left, 82 [degrees]; yaw right, 96 [degrees]; roll counterclockwise, 95 [degrees]; roll clockwise, 95 [degrees]; reserve tank, 75 [degrees]; manual tank, 70 [degrees]; auto tank, 78 [degrees]. [Isolated] bus voltage, 28½. |
| 02 21 41 | P | I am now drifting on the night side. I have the Moon in sight; I'm upside down; I'm observing lightning flashes from considerable-size thunder storms that are below me. These create static in the radio every time the lightning flashes down there. |

MUCHEA (SECOND PASS)

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|---|---|---|
| 02 24 13 | CC | Faith Seven, Muchea Cap Com. Over. |
| 02 24 18 | P | Roger, Muchea Cap Com. Faith Seven. |
| 02 24 21 | CC | Roger. Reading you loud and clear. Aeromed requests that you give him a mark when you begin your exercise and a mark when you stop your exercise. Over. |
| 02 24 30 | P | Roger. Will do. |
| 02 24 34 | CC | I have [recovery] area 3–1 retrosequence time, 02 58 05. Do you copy? |
| 02 24 46 | P | 02 58 05. Is that affirm? |
| 02 24 48 | CC | That's affirmative. |
| 02 24 55 | P | Roger. I'll be sending a blood pressure in just 1 second. |
| 02 24 58 | CC | Roger. |
| 02 25 43 | CC | Faith Seven. Systems reports that your suit [heat exchanger] dome temp is decreasing rather rapidly. Would you check that, please? |
| 02 25 51 | P | *Roger. I'll just decrease the flow on both cabin and suit here. |
| 02 25 57 | CC | Roger. We confirm here. |
| 02 26 08 | P | Roger. I'm getting the exerciser now. |
| 02 26 28 | P | Starting the exercise. |
| 02 26 55 | P | Ending the exercise now. |
| 02 26 57 | CC | Roger. |
| 02 27 01 | P | Sending blood pressure now. |
| 02 27 03 | CC | Roger. |
| 02 27 14 | CC | We're reading your cabin heat [exchanger] dome temp at 44 [degrees] now. |
| 02 27 19 | P | Roger. I concur. 44 [degrees] on cabin and about 47 [degrees] on suit. |
| 02 27 24 | CC | Roger. We concur here. |
| 02 27 44 | P | How does your med. like those blood pressures? |
| 02 27 50 | CC | Stand by. They report they look very normal. |
| 02 28 01 | P | Roger. |
| 02 28 25 | CC | Could you give me a cabin air temp reading? |
| 02 28 28 | P | Roger. Cabin air temp is 98 degrees. |
| 02 28 31 | CC | Roger. 98. |
| 02 28 33 | P | Roger. |
| 02 29 24 | CC | Do you have the Perth lights in sight? |
| 02 29 30 | P | One moment, let me get my cabin lights down. |
| 02 29 42 | P | Negative, I'm upside down. I can't see them. |
| 02 29 45 | CC | Roger. |
| 02 30 18 | CC | We have approximately 1 minute to LOS. |
| 02 30 22 | P | Roger. |
| 02 30 25 | P | Tell Warren not to get lost out in the outback. |
| 02 30 29 | CC | We almost got lost last Sunday. |
| 02 30 31 | P | Ha, ha! |
| 02 30 33 | ? | Astro, most of the boys have joined tennis clubs here. |
| 02 30 36 | P | Roger. This is more fun than tennis. |

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|---|---|---|
| 02 34 35 | P | Long status report . . . . . temperature: Let's see, first, retro 60 [degrees]; pitch down, 95 [degrees]; pitch up, 82 [degrees]; yaw left, 80 [degrees]; yaw right, 95 [degrees]; roll counterclockwise, 92 [degrees]; roll clockwise, 92 [degrees]; 250 inverter, 102 [degrees]; 150 inverter, 118 [degrees]; standby inverter, 98 [degrees]; cabin temperature, 98 [degrees]; suit inlet temperature, 60 [degrees]. Heat exchanger dome temperatures: cabin 50 [degrees]; suit, 48 [degrees]. Just then decreased flow and is coming back up. Main d-c bus, 24 volts; isolated [bus], 28 [volts]; current, 8 amps. It is 02 36 40. Milky Way is quite distinct. Now looking at the False Cross. Upside down, drifting flight at the moment. |
| 02 39 38 | P | *And I have the constellation of Sagittarius in sight. Nunki right there. There's the Moon directly in the top of my window. |

CANTON ISLAND (SECOND PASS)

| | | |
|---|---|---|
| 02 43 39 | CC | Faith Seven, Canton Cap Com. All systems look green on the ground. We're standing by. |
| 02 43 45 | P | Roger, Canton. All systems look green here, thank you. |
| 02 47 39 | CC | Faith Seven, Canton. |
| 02 47 41 | P | . . . Canton, Faith Seven. |
| 02 47 47 | CC | Seven, [contingency recovery area] 3–Alpha [retrosequence time] is nominal. |
| 02 47 50 | P | Roger, [contingency recovery area] 3–Alpha [retrosequence time is] nominal, thank you. |
| 02 48 33 | P | The time is 02 48 35 NOW [02 48 36]$^{T}$. Regulated pressure source on fuel, 475 [psi] auto; 490 [psi] on manual. Fuel, FQI 101 percent on auto; 102 percent on manual. Cabin dome temp, 50 [degrees]; suit dome temp, 50 [degrees]; cabin temp, 95 [degrees]; suit inlet temp, 60 [degrees]; cabin pressure holding at 5 psi. Main bus 24½ [volts]. I'm using 8 amps current. |
| 02 49 53 | P | Sunrise—and the sun is behind me, moving to the rear of me, with Saturn along by it. And I'm getting John's fireflies again, coming off the spacecraft. And you could almost aline yaw by the fireflies. They drift away to the rear of the spacecraft along to the rearward of the flight path. |
| 02 50 32 | P | Sunrise is coming in. |
| 02 51 38 | P | There's a coating of frost on the next to outside layer of window, which I believe, seems to be burning off as the sun hits the window. |

HAWAII (SECOND PASS)

| | | |
|---|---|---|
| 02 51 44 | CC | Faith Seven, Faith Seven, Hawaii Cap Com. How do you read? |
| 02 51 48 | P | Roger, Hawaii Cap Com. Reading you loud clear. |
| 02 51 52 | CC | Roger. Everything looks good on the ground. Your suit [heat exchanger] dome [temperature] is 54 degrees. Aloha from Hawaii. |
| 02 52 00 | P | Roger. Aloha to you, too. Everything appears to be normal here. |
| 02 52 04 | CC | Roger. We're standing by. |
| 02 52 07 | P | Roger. Thank you. |
| 02 53 37 | P | And after having entered the day side, I've drifted around where I'm looking towards the black sky. I have seen a star again, and I've been observing the fireflies drifting away. |
| 02 58 01 | P | I'm in bright daylight now, at 2 hours 58 minutes. I'm upside down. I still have, oh, about ½ degree per second roll rate—very, very, very light—almost ½ degree [1 sec] yaw, and pitch is oscillating between ¼ and ½ [degree/sec], close to the rate of roll. |

CALIFORNIA (SECOND PASS)

| | | |
|---|---|---|
| 02 59 55 | CC | Faith Seven, Faith Seven, this is California Cap Com. |
| 03 00 00 | P | . . . |
| 03 00 01 | CC | Faith Seven, Faith Seven. All systems here are green. You look real good here on the ground. Over. |
| 03 00 21 | P | . . . |
| 03 00 48 | CC | Faith Seven, Faith Seven. This is California, got you here, and you look real good all over on the board. The medics give you a clean bill of health. They would like to know if you just feel comfortable. Over. |
| 03 01 01 | P | Roger. I do feel comfortable, very comfortable. In fact, I had a little nap. |
| 03 01 06 | CC | Roger. We have a little news here from an old friend of yours, like Major Dick Shankle. Would you like to say hello? |

| | | |
|---|---|---|
| 03 01 14 | P | Hello, Dick. |
| 03 01 18 | CC | I'll pass that on, Gordo. |
| 03 01 20 | P | Roger. |
| 03 01 56 | CC | Faith Seven, we see you have powered up your ASCS; and also, I believe you are scheduled for tape recorder, continuous. |
| 03 02 06 | P | Roger. |
| 03 02 22 | P | Roger. Tape recorder is on continuous. |
| 03 02 25 | CC | Roger. Your clocks look real good here, in sync. No problems that we see. |
| 03 02 27 | P | I'm on fly-by-wire low. |
| 03 02 30 | CC | We see. |
| 03 02 31 | P | Roger. |
| 03 02 32 | CC | California standing by. |
| 03 02 34 | P | Roger. I'm alining the spacecraft, very slowly, to go to auto. Coming in over the coastline now; it's very clear; looks like very good weather down there with clouds standing off shore. |
| 03 02 54 | CC | Ha, ha! Roger. |
| 03 02 55 | P | I see the islands off shore. |
| 03 03 44 | CC | Attitudes look really good on the ground. You must have her alined real good. |
| 03 03 48 | P | Roger. |
| 03 04 00 | CC | Oh, wait a minute. Your gyros are still caged, aren't they? |
| 03 04 03 | P | That's affirm. |
| 03 04 11 | SY | Cabin heat exchanger outlet temperature. |
| 03 04 13 | CC | Systems requests a cabin outlet heat exchanger temperature. |
| 03 04 19 | P | Roger, cabin heat exchanger outlet is about 48 degrees. I've decreased the flow very slightly a few minutes ago and it should be easing on up. |
| 03 04 25 | CC | Roger. 48 [degrees] and you've decreased the setting. |
| 03 05 54 | P | Okay. I'm just about in attitude here, getting ready to uncage the gyros. |
| 03 07 19 | P | I am on auto orbit. |

CAPE CANAVERAL (THIRD PASS)

| | | |
|---|---|---|
| 03 07 32 | CC | Faith Seven, Cape Cap Com. |
| 03 07 35 | P | Roger, Cape Cap Com, Faith Seven. |
| 03 07 38 | CC | Roger. Read you loud and a little garbled. |
| 03 07 42 | P | Roger. |
| 03 07 44 | CC | Like to send you a T/M command, Gordo. |
| 03 07 46 | P | Roger. Go ahead. |
| 03 07 54 | CC | I have about three requests from you, cabin temperature? |
| 03 07 59 | P | Roger. Cabin temp is 92 degrees. |
| 03 08 03 | CC | Read 92. |
| 03 08 05 | P | Roger. |
| 03 08 07 | CC | Have you had any results on your KK clamp release? |
| 03 08 11 | P | Negative. I could not see any flow at all on it, so I clamped it off as planned. |
| 03 08 18 | CC | Roger, would you give us a readout of your cabin dome? |
| 03 08 21 | P | Roger. Cabin dome [temperature] is about 46 [degrees]. I have increased the flow slightly on it. Suit is 50 [degrees]. |
| 03 08 30 | CC | Roger. |
| 03 08 33 | P | I mean I have decreased the flow on cabin. |
| 03 08 41 | CC | I'd like to give you a time hack, if you will. |
| 03 08 43 | P | Roger. |
| 03 08 45 | CC | Give you an elapsed time first at 50 seconds, that will be 3 hours, 8 minutes, 50. 2, 1, MARK. (03 08 52) T |
| 03 08 53 | P | Roger. I'm 1 second fast. |
| 03 09 02 | CC | Roger, 1 second fast. |
| 03 09 03 | P | I am on auto orbit. |
| 03 09 06 | CC | Roger. Getting into attitude. Your attitude looks good here. |
| 03 09 14 | P | *Roger. I've got my gyros alined very easily and went on auto; and the auto appears to be a little bit slow to move it into the smaller gates but it's working very nicely. |
| 03 09 30 | CC | Good. |
| 03 09 34 | P | TV camera coming on now. |

| | | |
|---|---|---|
| 03 09 39 | CC | I'll give you a G.m.t. hack in a few seconds. |
| 03 09 42 | P | Roger. |
| 03 09 43 | CC | 16 hours and 14 minutes. 2, 1, MARK. (03 09 48)[T] |
| 03 09 54 | P | Roger. What was that, 14 minutes? |
| 03 09 56 | CC | That's 16 hours, 14 minutes, 00 second. |
| 03 09 59 | P | Roger. On my standby clock I am about 10 seconds slow on that. |
| 03 10 11 | CC | Is this your G.m.t. clock? |
| 03 10 15 | P | Roger. Both of them—no on the wrist watches—both of my wrist watches are together; however, they are a little slow. I have 14 30 NOW. (03 10 31)[T] |
| 03 10 34 | CC | Say again, Faith Seven. |
| 03 10 35 | P | Never mind I'll catch you later. |
| 03 10 38 | CC | Okay. |
| 03 11 01 | CC | Faith Seven, Cap Com. |
| 03 11 04 | P | Go ahead Cap Com, Faith Seven. |
| 03 11 05 | CC | I have [recovery area] 3–2 [retrosequence] time if you're ready to copy. |
| 03 11 09 | P | All right, just a moment. |
| 03 11 27 | P | Go. |
| 03 11 32 | CC | Faith Seven this is Cape Cap Com. We have had four R and Z cals. Request you turn your R and Z cal switch off. |
| 03 11 39 | P | Roger. |
| 03 11 49 | P | Go ahead on the [recovery area] 3–2 [retrosequence] time. |
| 03 11 59 | P | Cape Cap Com. Faith Seven ready to copy 3–2 time. |
| 03 12 29 | CC | Faith Seven, Cape Cap Com. |
| 03 12 33 | P | Roger Cape, go ahead. |
| 03 12 34 | CC | Did you copy my 3–2? I did not read you. |
| 03 12 37 | P | Negative, I didn't copy it. |
| 03 12 39 | CC | Roger. It's 04 hours + 08 minutes + 10 seconds. |
| 03 12 46 | P | Roger. 04 08 10. |
| 03 12 50 | CC | That's correct. |
| 03 13 15 | CC | Faith Seven. Your scanners and attitudes agree very nicely. Over. |
| 03 13 27 | CC | Faith Seven, Cape Cap Com, you can turn TV off. |
| 03 13 32 | PC | Roger. I already have it off. |
| 03 13 43 | CC | Faith Seven, Cape Cap Com. |
| 03 13 47 | P | Go ahead Cape, Faith Seven. |
| 03 13 49 | CC | Are your tower sep lights and cap sep lights out? |
| 03 13 52 | P | Affirm. |
| 03 13 54 | CC | Roger. |
| 03 13 56 | P | They went out at 314.5. |
| 03 14 00 | CC | Roger. They should have been. We just had a T/M, and we wondered why. |
| 03 14 02 | P | Roger. |
| 03 14 03 | CC | No problem on these at all. |
| 03 25 06 | P | *I am on fly-by wire, have armed the squib, pitching up very, very slowly, and will deploy the flashing light at the —20 degree point. Flashing light is deployed. I'm marking the tape. Deploy light off. Squib is off. Gyros are caged, free to caged. Roger—and ASCS a-c bus off. NOW. [03 26 28][T] Stick is now cold. |
| 03 27 01 | CC | . . . Cape Cap Com. Do you read? Over. . . . Do you read? Over. . . . |
| Unreadable | CC | Faith Seven . . . on relay. Do you read? Over. |
| Unreadable | CC | Faith Seven . . . do you read? |
| 03 28 15 | P | *ASCS inverter, 110 [degrees] when I powered it down. Sitting at 90 degrees yaw right now. It is easy to determine that the angle is very large, so far as telling to a high degree of accuracy, in a short time; but I am yawing around to observe the flashing light on the night side—is very easy to determine that, it is about 90 degrees yaw, now. I'm getting directly away from the Sun now, observing the night side coming on. With the window head on, I can see the demarcation line between the Sun and the light side and the dark side. Light blue above the Earth, and a band of blue above the Earth that fades in the dark side. Observing fireflys taking off now. And there's a very, very distinct demarcation now. |
| 03 37 17 | P | At this point I have no way of knowing what my yaw is. Left cabin light only, with the red filter . . . |
| 03 51 29 | P | *I still have not observed the flashing light. I have Sagittarius right in the middle of the window. It is directly on my 80 degree yaw . . . . |

## MUCHEA (THIRD PASS)

| | | |
|---|---|---|
| 03 58 33 | CC | Faith Seven, Muchea Cap Com. |
| 03 58 37 | P | Go ahead, Muchea, Faith Seven. |
| 03 58 39 | CC | Roger. Will you confirm that your squib switch is off? |
| 03 58 49 | P | Affirm. Squib switch is off. |
| 03 58 52 | CC | Roger. Area [contingency recovery] 4–A [retrosequence] time is nominal. |
| 03 59 00 | P | Roger. Thank you. |
| 03 59 05 | CC | Aeromeds are standing by for your blood pressure. |
| 03 59 08 | P | Roger. Sending it now. |
| 03 59 13 | CC | Roger. |
| 03 59 16 | CC | Did the beacon deploy? |
| 03 59 20 | P | Affirmative. I'm still trying to find it out here in the dark. |
| 03 59 25 | CC | You haven't seen the light. Is this true? |
| 03 59 28 | P | Negative. I still haven't found it. Still looking, though. |
| 03 59 37 | CC | Roger. |
| 04 00 34 | P | Everything is nominal on this trip, Muchea. I don't believe anything went wrong at all. |
| 04 00 38 | CC | Roger. Understand. T/M reports you green here. |
| 04 00 46 | P | Roger. |
| 04 00 49 | CC | Aeromed the same. |
| 04 00 52 | P | Roger. Thank you. |
| 04 01 17 | CC | Faith Seven. How do you know that the beacon has deployed? |
| 04 01 22 | P | I felt it deploy. |
| 04 01 24 | CC | Roger. |
| 04 01 27 | P | I don't know which deployed the fastest, me or it. |
| 04 01 28 | CC | Ha, ha, ha! Roger. |
| 04 01 51 | P | I am directly on my 180 [degree] yaw, and with the Moon in the upper left hand corner of the window. |
| 04 02 00 | CC | Say again, Faith Seven. |
| 04 02 02 | P | . . . 180 degrees, and still haven't seen it. |
| 04 02 05 | CC | Would you say again your attitudes? |
| 04 02 07 | P | Roger. I'm zero roll, about —34 degree pitch, and yaw at 180 degrees. Small end forward. |
| 04 02 17 | CC | Roger, and you still haven't found the light? |
| 04 02 20 | P | Negative, still haven't found it. |
| 04 04 08 | CC | Faith Seven, Muchea Cap Com. We're approaching LOS. You found the light yet? |
| 04 04 14 | P | Negative. Not yet. |
| 04 05 49 | P | I am now yawed 180 degrees, 0 [degrees] roll, I have a very slight roll attitude into the right. The Moon is in the upper left hand corner of the window—the—directly on my 180-degree path; I'm not able to see the flashing light. I am observing the haze layer again that Wally described. At this time I am still looking for the light. I'm observing lightning flashes on the ground, down on Earth that is. Considerable cloud cover. Venus and Jupiter in the left-hand part of the window. |
| 04 15 00 | P | I should still be right on track, on the 180-degree yaw. Still no flashing light, and I'm beginning to get the brilliant blue of Sun rising in the East. Bright blue band underneath all this haze layer. I can see the haze layer, and the bright band of light demarcation coming underneath it. Quite distinctive. There's a faint greenish tint to it where there are clouds, apparently. |

## HAWAII (THIRD PASS)

| | | |
|---|---|---|
| Unreadable | CC | Faith Seven, Faith Seven, this is Hawaii. |
| 04 16 39 | P | Roger, Hawaii. Faith Seven reading you loud and clear. Roger, understand. |
| Unreadable | CC | Roger. Is your C-band beacon in a continuous position? |
| Unreadable | P | Negative. I have it on ground command. I'll bring it to continuous, now. |
| Unreadable | CC | Roger. On my mark will you switch your TV control switch to T/M, and read out your fuel and $O_2$ quantities? |
| Unreadable | P | Roger. Will do. |
| 04 17 28 | P | Roger. I am just small end forward. 180-degree yaw, approaching sunrise. Over. |
| Unreadable | CC (CNV) | Faith, Faith Seven, this is Cape Cap Com on Hawaii transfer for check. How do you read me, over? |
| Unreadable | P | Roger. Reading you loud and clear, Cape Cap Com. |
| Unreadable | CC (CNC) | Roger, Gordo. Pretty long talk-line here. |

| | | |
|---|---|---|
| Unreadable | P | You're right. |
| Unreadable | CC | Stand by for my mark. MARK 04 23 35. Switch your TV control switch to T/M. |
| Unreadable | P | . . . now going over TV transmitter. |
| Unreadable | CC | Roger. |
| Unreadable | P | Roger. These small particles drift away from you, small end forward. In this light they appear brilliant white, without green at all in them. They appear to move on out, and around back toward the flight path. |
| Unreadable | CC | We're standing by for your readout of fuel and $O_2$. |
| Unreadable | P | Roger. My auto fuel, I have 96 percent; on manual, I have 102 percent. On oxygen I have 90 percent on primary and 100 percent on secondary. |
| Unreadable | CC | Roger. We understand. We also have a message from the Cape. It's possible that you only felt the squib blow and not the beacon deploy. Is there any way that you might check this? |
| 04 24 31 | P | Not from in here, I don't think. |
| 04 24 34 | CC | Roger, you haven't see the beacon at this time. |
| 04 24 37 | P | Negative. I still haven't seen the beacon. |
| 04 24 40 | CC | Check. |
| 04 24 46 | P | There was considerable noise, though, as if something were departing. |
| 04 24 50 | CC | Say again, Seven. |
| 04 24 52 | P | * There was considerable noise, which sounded like those doors blowing open so I assume the beacon has departed. |
| 04 24 58 | CC | Roger, understand. |
| 04 24 06 | CC | T/M looks real good on the ground. |
| 04 25 08 | P | Roger. |

CALIFORNIA (THIRD PASS)

| | | |
|---|---|---|
| 04 33 15 | CC | Faith Seven, this is California Cap Com. Over. |
| 04 33 18 | P | Roger, California. Faith Seven. |
| 04 33 21 | CC | Roger, Faith Seven. Systems and medics are go here. |
| 04 33 26 | P | Roger. My date [flight plan] put my telemack to normal [switch position] . . . |
| 04 33 35 | CC | Roger. Just, just stand by a second until systems finish marking the meters. |
| 04 33 45 | P | . . . |
| Unreadable | CC | All right, at my mark then would you switch. I'll start a countdown then. 9, 8, 7, 6, 5, 4, 3, 2, 1, MARK. |
| Unreadable | P | Roger. . . . |
| Unreadable | CC | Okay. You confirm TV control switch to off? |
| Unreadable | P | Roger. TV control is off. |
| 04 34 33 | CC | We had a slight decrease in the two links on d-c current. Would you give us a readout? |
| 04 34 41 | P | Roger. D-c current: the main bus is 24 [volts]; isolated [bus], 28½ [volts]. |
| 04 34 50 | CC | Roger. |
| 04 35 32 | CC | California standing by. |
| 04 35 35 | P | Roger. |
| Unreadable | P | . . . can see all up and down the California coast, here . . . very clear. |
| 04 36 29 | CC | Roger. |
| 04 36 43 | CC | I seem to have a little discrepancy between c.e.t. and g.e.t. You're 2 seconds fast according to my clock. |
| 04 36 59 | P | . . . I'll give you a mark . . . 4 37. |
| Unreadable | CC | Roger. |
| Unreadable | P | 2, 1, MARK [Unreadable]T |
| 04 37 04 | CC | Right. The ground shows that your readout there is confirmed with ground. However, it is 2 seconds fast from our g.e.t. |
| Unreadable | P | Roger. |

CAPE CANAVERAL (FOURTH PASS)

| | | |
|---|---|---|
| 04 40 04 | CC | Faith Seven, Cape Cap Com. |
| 04 40 08 | P | Roger, Cape Cap Com. Faith Seven. |
| 04 40 24 | P | Roger, Cape Cap Com. Faith Seven here. |
| 04 40 27 | CC | Faith Seven. Cape Cap Com. Would you turn on your TV immediately? |
| 04 40 32 | P | Roger. Will do. |

| | | |
|---|---|---|
| 04 40 38 | P | Faith Seven passing just about over Houston now. |
| 04 40 45 | CC | And would you program R and Z cal to auto. |
| 04 40 53 | P | Roger. TV coming on now. R and Z cal programer coming to auto. |
| 04 41 01 | CC | Understand TV on; R and Z cal to auto. |
| 04 41 13 | CC | Seven, from Cape. Could you give us your best coolant valve settings, please. |
| 04 41 22 | P | Roger. Stand by 1 minute. |
| 04 41 42 | P | Roger. I'm below the nominal on the suit. I'm using about the 1¾ on suit. |
| 04 41 54 | CC | That's 1¾ on suit. |
| 04 41 55 | P | Roger, and using about 3.0 on the cabin. |
| 04 42 01 | CC | Understand 3.2 on the cabin. |
| 04 42 06 | CC | Give you [recovery area] 4–1 retro time. 05 43 41. |
| 04 42 14 | P | Roger. 43 41. |
| 04 42 16 | CC | Roger. |
| 04 42 22 | CC | Have you consumed any water up to this point? |
| 04 42 26 | P | Roger. I'm also giving the doctors their first space sample. For the Electro-Chancellor System, that is. |
| 04 42 43 | CC | Roger. We understand. We may send up another one; we understand you're full. |
| 04 42 49 | P | Roger, who are you sending up with it? |
| 04 42 59 | CC | Seven, Cap Com. We'd like a cabin temp, cabin heat exchange outlet temp, and three $H_2O_2$ tank temps. |
| 04 43 14 | P | Roger. Cabin outlet is 42 degrees. |
| 04 43 22 | CC | Roger. |
| 04 43 24 | P | Peroxide auto tank is 80 degrees. Manual tank is 70 degrees. Reserve tank is 75 degrees. What else do you want? |
| 04 43 40 | CC | Like to know about the cabin air. |
| 04 43 44 | P | Roger. Cabin air temp is 90 degrees. |
| 04 43 48 | CC | Understand, 90 degrees. |
| 04 43 52 | CC | Gordo, this is Wally. Did you have anything to eat? |
| 04 43 54 | P | Negative, not yet. I'm planning to shortly, here, though. |
| 04 44 02 | CC | Roger. For your information, systems' last computations on fuel at Hawaii give 88 [percent] auto, 98 [percent] manual, which is somewhat better than you're indicating on board. |
| 04 44 17 | P | Roger. On board I'm indicating 96 and 102. |
| 04 44 38 | P | Oh, boy what a beautiful shot of Florida. |
| 04 44 44 | CC | Roger. Looks good from here once in awhile too. |
| 04 44 46 | P | *Roger. The whole state is clear. I can see just about all of it. It's been a beautiful view coming over Florida. |
| 04 44 55 | P | . . . looks very good. |
| 04 45 01 | CC | Roger. |
| 04 45 05 | P | . . . |
| 04 45 12 | CC | Roger, Faith Seven. |
| 04 45 34 | CC | Faith Seven, this is Cape Cap Com. We are very impressed with the work you're doing. |
| 04 45 42 | P | Thank you. |
| 04 45 47 | CC | We lay a pat on the back from Walt Williams. |
| 04 45 52 | P | Thank you. |
| 05 05 03 | P | Now on 180 [degrees] yaw. I got here on manual proportional control. I'm at last daylight, going into dark. Have been looking for the flashing beacon. 05 05 18 NOW, [05 05 17]$^T$ 28, I'm sorry, not 18. That light in sight—it is below me. It is quite a brownish, reddish brown and considerable altitude above the ground. Every time I fire a pitch down thruster, I get a shower of these little fireflies. The light is flashing now. It is the light. It's quite bright, quite discernible . . . 1, 2, 3, 4, 5, 6, 7, rate. It appears to be about—it appears to be about 10 to 12 miles away. I'm keeping it directly in the window. About the order of a second magnitude star, NOW. [05 11 34]$^T$. Light is still in sight, directly in the center of the window. In the background I can make out a lot of cumulus activities, faced of course to the easterly direction at 180 degrees yaw. |

| | | |
|---|---|---|
| 05 13 40 | P | *The Milky Way is quite distinct. I can see it out the window. The Milky Way is quite distinctive. It's right in the center of the window. Quite noticeable. 05 16 35 NOW. [05 16 35]$^{T}$ Light is still in sight. Moved off from it and then moved back using it for visual—to see if I could pick it up. I am able to pick it up. . . . thunderstorms all in under it at the moment. It is quite distinctive. 05 18 05 NOW. [05 18 05]$^{T}$ Status report: retro temperature, 62 [degrees]; pitch down is 82 [degrees]; pitch up is 72 [degrees]. Yaw left, 75 [degrees]; yaw right, 90 [degrees]. Roll counterclockwise, 92 [degrees], clockwise, 90 [degrees]. Main inverter temp., 98 [degrees]; fans inverter temp., 120 [degrees]; standby inverter, 98 [degrees]. The squeezers are working again as advertised. Okay, the cabin and suit temperature: the cabin air is 90 [degrees]; suit inlet temp. is 61 [degrees]. Heat-exchange dome temperatures: cabin, 56 [degrees]; suit, 56 [degrees]. D-c bus, 24 [volts]; isolated bus, 28 [volts]; and reading 7 amps, current. |
| 05 34 58 | P | *5 hours and 34 minutes; now it's 35 minutes MARK. [05 35 10]$^{T}$ Am drifting now. Do have the light in sight at the moment, apparently right on track. I see Antares on up ahead of me, which indicates that I am on the 180-degree drift point. See Corona Australis and, saw Sagittarius with Nunki apparently. 5 hours 39 minutes 30 seconds, MARK. [05 39 31]$^{T}$ |
| 05 39 36 | P | Have the little flashing light still in sight, out ahead of me. About the order of a first magnitude star, now. It's not very discernable . . . due to the flashes. However, it can be picked up. It appears like it's around 13—13 to 14 miles. |

HAWAII (FOURTH PASS)

| | | |
|---|---|---|
| 05 41 38 | ? | [Unintelligible, foreign language transmission recorded here.] |
| 05 51 15 | P | . . . there. |
| 05 51 44 | CC | Hello, this is Hawaii transmitting on air to ground relay. Do you read? |
| 05 58 35 | CC | Faith Seven, Faith Seven, Hawaii Cap Com. Over. |
| 05 58 52 | P | Roger, Hawaii Cap Com. Faith Seven, here. Over. |
| 05 58 56 | CC | Roger. Faith Seven. May we have an oral temperature at this time and also a readout of fuel and $O_2$ quantities? |
| 05 59 03 | P | Roger. . . . |
| 05 59 06 | CC | Roger. It looks good down here. Reading 100 [degrees]. |
| 05 59 11 | P | Roger. |
| 05 59 19 | CC | Standing by for a fuel and $O_2$ quantity. |
| 05 59 24 | P | Roger. Auto fuel, 94 percent; manual fuel, 102 percent. Oxygen primary about 89 percent; secondary, 100 percent. |
| 05 59 43 | CC | Roger. Are you—are you in drifting flight? |
| 05 59 47 | P | That's affirm. I'm in drifting flight. |
| 05 59 50 | CC | Roger. Retrosequence time for [contingency recovery] area 5–A is nominal. |
| 05 59 55 | P | Roger. 5–A is nominal. Thank you. |
| 06 00 17 | CC | Seven. Cape has just advised you have enough time for 92 orbits. |
| 06 00 27 | CC | Hawaii, standing by. |
| 06 00 30 | P | Roger. |
| 06 00 50 | CC | Seven, this is Hawaii. Have you seen the beacon yet? |
| 06 00 54 | P | Affirm. I was with the little rascal all night last night. |
| 06 00 58 | CC | Roger. Very good. |
| 06 01 01 | P | I tracked it the first part of the night, and then went into drifting flight and then picked it up the last part of the night again. Over. |
| 06 01 07 | CC | Very good. |

CALIFORNIA (FOURTH PASS)

| | | |
|---|---|---|
| 06 05 55 | CC | Faith Seven, this is California Cap Com. |
| 06 05 59 | P | Roger, California Cap Com. Faith Seven here. |
| 06 06 02 | CC | Roger. Systems and aeronmedics give you a go here; and I'd like to check position on your C-band switch. |
| 06 06 24 | P | Roger. C-band is on continuous. Over. |
| 06 06 28 | CC | Read you. That's continuous? |
| 05 06 29 | P | That's affirmative. |

| | | |
|---|---|---|
| 06 06 39 | CC | Would you please change your S—C-band beacon switch to ground command. |
| 06 06 43 | P | Roger. Going to ground command. |
| 06 06 48 | CC | On your schedule, for a B.P. [blood pressure] over this station. |
| 06 06 52 | P | Roger. You ready? |
| 06 06 55 | CC | We are. Roger. |
| 06 08 31 | CC | Aeromeds said they received the B.P. and would you turn it off. |
| 06 08 35 | P | Roger, will do. |
| 06 08 37 | CC | Would you give me a reading on your cabin $PO_2$ pressure? |
| 06 08 42 | P | Roger. Partial pressure of oxygen is about 4.4 [psi]. |
| 06 08 46 | CC | Roger. Thank you. |
| 06 09 35 | CC | Five Baker, Five Charlie, and five . . . [contingency recovery area retrosequence times] are nominal. |
| 06 09 40 | P | Roger, thank you. |
| 06 10 14 | CC | . . . |
| 06 10 19 | P | Roger. |
| 06 10 26 | P | Roger, go ahead. |
| 06 10 30 | CC | . . . +17 + 09. |
| 06 10 35 | P | Roger. 07 17 09. |
| 06 10 38 | CC | Affirm. |

CAPE CANAVERAL (FIFTH PASS)

| | | |
|---|---|---|
| 06 14 40 | CC | Faith Seven, Cape Cap Com. Do you read, over? |
| 06 14 45 | P | Roger, Cape Cap Com. Faith Seven, here. |
| 06 14 53 | CC | Faith Seven, Cape Cap Com. Over. |
| 06 14 56 | P | Roger, Cape Cap Com. Faith Seven, here. |
| 06 15 01 | CC | Faith Seven, Cape Cap Com. Over. |
| 06 15 05 | P | Roger, Cape Cap Com. Faith Seven reading you loud and clear. |
| 06 15 09 | CC | Faith Seven, Cape Cap Com. Over. |
| 06 15 17 | P | Roger, Cape. Faith Seven is reading you loud and clear. How me? Over. |
| 06 15 21 | CC | Roger, Gordo. Read you same. Assume you have TV on. Are you looking out the window? |
| 06 15 25 | P | Affirmative. |
| 06 15 28 | CC | Can just see horizon line, sort of interesting. |
| 06 15 38 | CC | Gordo, how did the manual control check work out? |
| 06 15 45 | P | Worked out fine. |
| 06 15 46 | P | Very good. You're looking beautiful on fuel. |
| 06 15 49 | CC | Roger. |
| 06 15 50 | CC | Environment tells us that you are using about 4-percent oxygen per hour, indicated. Over. |
| 06 15 59 | P | Roger. It looks that way here. |
| 06 16 04 | CC | Well this is a computation that will show later on. This is as much as you're using. |
| 06 16 10 | P | This is 4 percent of your 200 percent.<br>Roger. |
| 06 16 12 | CC | We'd like to have a brief rundown on the acquisition of the beacon if you acquired and an idea of about what distance away you would guess that it was. |
| 06 16 22 | P | Roger. When last I saw it, in the last orbit, looked like it was about 12 to 13 miles away. I first thought that it looked like it was about 8 or 10 miles away. And at the last it was getting fairly dim, about the order of a fourth or fifth magnitude star. |
| 06 16 43 | CC | Roger. |
| 06 16 46 | P | When I first . . . looked like a magnitude star. |
| 06 16 51 | P | There's Florida, should. . . . |
| 06 16 54 | CC | Roger. We're getting a pretty good picture on this, this time. |
| 06 16 56 | P | Roger. |
| 06 16 58 | CC | I'd say your f stop is ideal. |
| 06 17 09 | CC | Gordo, how did you initially acquire the beacon? Did it just come in your field of view? |
| 06 17 14 | P | Roger . . . . |
| 06 17 21 | CC | Roger, understand. |
| 06 17 23 | P | There it was. |
| 06 17 27 | CC | That was during the night side of this last orbit. Is that correct? |
| 06 17 37 | CC | Faith Seven, Cape Cap Com. |
| 06 17 40 | P | Go ahead, Cape. |

| | | |
|---|---|---|
| 06 17 41 | CC | You acquired it during the night side of this past orbit. Was that correct? |
| 06 17 44 | P | It's affirmative. Just at night. |
| 06 17 47 | CC | You can see it only at night. |
| 06 17 49 | P | I acquired it just as it got dark, right. |
| 06 17 52 | CC | Very good. |
| 06 17 53 | P | It was just getting dark when I acquired it. It was shining, there was still sunlight and I could see it shining before I could see it flash, so apparently it had some light reflected off of it. |
| 06 18 04 | CC | Roger. Understand. |
| 06 18 30 | P | Roger. Turning off [TV] camera now. |
| 06 18 39 | P | Go ahead, Cape. |
| 06 18 43 | P | Go ahead, Cape, Faith Seven. |
| 06 18 52 | P | Roger, Cape. Faith Seven reading you loud and clear. |
| 06 25 40 | P | At 6 hours and 22 minutes I turned off the cabin coolant and the cabin fan. Now I'm preparing to eat a little bite. The sandwiches that I am looking at here are pretty crumbly, lot of crumbs floating all over in the bag that they're in. I may not open them. |
| 06 32 23 | P | *I just had two pieces of Brownie and nut, small cakes, and just now eating bacon. Will drink some water following this. |
| 06 35 15 | P | I have just drunk six or seven large sips of water from the McDonnell drinky drink. |
| 06 54 31 | P | * And it's 6 hours 54 minutes 37 seconds NOW. [06 54 38].[T] I have the flashing light in sight again—extremely weak, very, very weak. Actually, just barely discernible. I would estimate it to be somewhere in order of 18 to 20 miles away. The Moon is out, and the water is very, very bright, below. It's quite a lovely moonlit night. |
| 07 03 39 | P | Right on the flight plan, there's our old friend Delphinus. I am drinking water at 07 08 00, very fine. Took seven or eight large swallows from the McDonnell tank. |
| Unreadable | CC | . . . |
| 07 18 09 | P | *I was just called by CSQ and informed that Cape desired to leave C-band beacon off. |
| Unreadable | CC | . . . |
| Unreadable | P | Short report. Nitrogen low pressure: auto, 475 [psi]; manual 4 . . . B-nut: Pitch-down is 80 [degrees]; pitch up, 70 [degrees]. Yaw left is 72 [degrees]; yaw right is 75 [degrees]. Roll counterclockwise is 78 [degrees]; roll clockwise is 75 [degrees]. And auto tank temp., 79 [degrees]; manual tank, 71 [degrees]; reserve tank, 75 [degrees]. Isolated bus voltage, 28. |

## HAWAII (FIFTH PASS)

| | | |
|---|---|---|
| Unreadable | CC | Hello Faith Seven. Faith Seven, Hawaii Cap Com. Do you read? |
| Unreadable | P | Roger, Hawaii Cap Com. Loud and clear. |
| 07 31 50 | CC | Roger. Faith Seven, this is Hawaii Cap Com. For your information, all your experiments should be on time; you have two-tenths cloud coverage for the light experiment. Your electrical power usage has been below expected. [Contingency recovery] area 6–A [retrosequence time] is nominal. Stand by to copy [recovery area] 6–1 [retrosequence] time, 08 50 17. Did you copy? |
| 07 32 08 | P | 08 50 17, for 6–1. |
| 07 32 13 | CC | Roger, and 6–Bravo is also nominal. Will you turn your beacons to ground command at this time and give me a readout on your fuel and oxygen quantities, also your peroxide reducer [regulated] pressure, auto and manual? Over. |
| 07 32 34 | P | Roger. Say again on the beacon. What do you want on them? |
| 07 32 39 | CC | Roger. Will you put your beacons to ground command at this time? |
| 07 32 43 | P | Roger. Beacons are on ground command. Peroxide regulated pressure: 475 [psi] on auto; 490 [psi] on manual. . . . $0_2$ percent on manual; oxygen is 191 percent on primary, and 100 [percent on secondary]. |
| 07 33 12 | CC | Roger, give me your fuel again please, Gordo. |
| 07 33 15 | P | Fuel is auto, 90 [percent], manual, 102 [percent]. |
| 07 33 24 | CC | Roger. We've copied all. Did you turn your T/M on for CSQ? Over. |
| 07 33 39 | P | . . . |
| 07 33 42 | CC | Say again, Gordo. |
| 07 33 44 | P | Negative, I did not turn my T/M on for CSQ. |
| 07 33 48 | CC | Roger. They did report getting a short burst. Will you please leave T/M off for all periods greater than 30 minutes; no contact with ground stations. |
| 07 33 52 | P | Roger. |

| | | |
|---|---|---|
| 07 34 15 | CC | Faith Seven, Hawaii Cap Com. Do you read? |
| 07 34 17 | P | Roger, Hawaii. |
| 07 34 19 | CC | Roger. I have [recovery area] 7–1 and 8–1 [retrosequence] times. Do you read? |
| 07 34 23 | P | Roger. Go. |
| 07 34 25 | CC | 7–1 is 10 23 33. 8–1 time is 11 56 24. Did you copy? |
| 07 34 37 | P | Roger. 7–1 is 10 23 33; 8–1 is 11 56, and what was the second? |
| 07 34 46 | CC | 24. |
| 07 34 48 | P | 24, Roger. |
| 07 34 49 | CC | Roger. You're looking fine on the ground, Gordo. |
| 07 34 53 | P | Roger. Thank you. I saw the flashing beacon again last night. |
| 07 34 58 | CC | Roger. I understand you saw it throughout? |
| 07 35 00 | P | I saw the flashing beacon again last night. |
| 07 35 04 | CC | Roger. Understand. |
| 07 40 22 | P | *In auto orbit. I'm pumping the condensate tank out; and will open the KK clamp. Two strokes, both syringes full, third full syringe full, four syringes full, five syringes full. |

CALIFORNIA (FIFTH PASS)

| | | |
|---|---|---|
| 07 40 52 | CC | Faith Seven, this is California Cap Com. |
| 07 40 55 | P | Roger, California. Faith Seven here. |
| 07 40 58 | CC | Roger. Faith Seven. Schedule for B.P. [blood pressure], exercise, and a B.P.'s. |
| 07 41 03 | P | Okay, you ready? |
| 07 41 04 | CC | Roger. |
| 07 41 06 | P | Understand. |
| 07 41 09 | CC | Same exercise as Muchea is requested by the medics. |
| 07 41 13 | P | Roger. |
| 07 41 59 | P | Here comes the exercise. |
| 07 42 12 | P | Starting exercise now. |

GUAYMAS (FIFTH PASS)

| | | |
|---|---|---|
| 07 42 28 | CC | Faith Seven, Guaymas Cap Com. |
| 07 42 29 | P | Roger, Guaymas. |
| 07 42 32 | CC | Roger, Gordo. Have a little information to pass on to you. |
| 07 42 36 | P | Roger. Let me get my exerciser stored back in here. |
| 07 42 39 | CC | Roger. You through? |
| 07 42 40 | P | Blood pressure coming now, Cal. |
| 07 42 53 | P | Roger. I'm through with this. |
| 07 42 56 | CC | Roger. We would like to remind you to pump out your condensate and turn on your water wick at about 8 hours. |
| 07 43 04 | P | Roger. |
| 07 43 06 | CC | And would you give us oral temperature over CSQ. Start taking your temperature at about—elapsed time of—at about 08 45. |
| 07 43 18 | P | Roger. Over CSQ. Is that affirm? |
| 07 43 20 | CC | Roger. We want to get one over CSQ. |
| 07 43 25 | P | Roger. |
| 07 43 26 | CC | And the Cape would like to remind you to keep your T/M turned off when you're out of contact with stations. They're trying to keep a close track of the power you've used. |
| 07 43 35 | P | Roger. |
| 07 43 39 | CC | And you can turn off your blood pressure now. |
| 07 43 51 | CC | Did you read that, Gordo? |
| 07 43 53 | P | Roger. |
| 07 43 58 | P | You said turn off the blood pressure. Right? |
| 07 44 00 | CC | Roger. And you can power up your ASCS bus anytime. |
| 07 44 03 | P | Roger. Stand by. |
| 07 44 14 | P | Roger. Powered up. 120 volts. |
| 07 44 19 | CC | Roger, we can—you're okay down here. |
| 07 44 26 | P | Okay. |
| 07 45 51 | CC | Gordo, have you cut anything off? We get—just got a drop in current. |
| 07 45 57 | P | Negative. |
| 07 45 58 | CC | Roger. |
| 07 46 03 | P | I have ASCS a-c bus powered up. It draws more current when it starts, I suppose. |
| 07 46 09 | CC | Roger, I guess that's it. |

| | | |
|---|---|---|
| 07 59 04 | P | *Scanners are not working very rapidly. Spacecraft is yawed to the left very, very, except in yaw is, all right I mean. Correction, is rolled to the left about 10 degrees and the gyros read okay. Here comes some correction in now. They're beginning to correct. And this syringe full is about full. There is a lot of air in it; this is the last one I'll take out. |
| 08 00 47 | P | I'll add it on to all the others, I believe that's 5½. Took 10 large swallows of water. And I am now opening the Kenney Kleinknecht clamp. |
| 08 16 09 | P | *Peroxide reserve tank is 72 degrees. Peroxide manual tank, 70 degrees; peroxide auto is 78 degrees. Cabin outlet is 66 [degrees]. 250 inverter is 105 [degrees]; 150 inverter is 120 [degrees]; standby inverter is 95 [degrees]. Oxygen, 90 and 100 [percent]. Fuel, 86 and 102 [percent] . . . Here, I have the light in sight, in the top portion of my window. Extinctometer reading I got was—not any good there, blocking out by the top part of the window. . . . I did observe the ground light; it's quite bright. |
| 08 23 25 | P | Very recognizable in the little town. A little horseshoe shaped town was quite distinctive; it was right beside it. |
| Unreadable | P | *Now in auto reentry. Gyros going to slave. I got there in fly-by-wire low to 0, 0, 0 [degrees], selected auto reentry, and have now put the gyros to slave. |
| 08 26 15 | P | *Manual pitch plane precession was a little too great, as the gyros are torquing a little bit of negative pitch in here to correct for the pitch torquing . . . overage. The damn desk is unusable; it's too far down on the lap, and it will not lock down. My legs are in the way at zero g. Cannot bring it down to lock down. |
| 08 35 35 | P | *There seems to be some difficulty with the number two urine collection bag. It's very difficult to pump more than the 1½ syringes full that I got into it. And I hear a hissing back behind me; so I suspect there is too much pressure on it, and I'm going to cease on this one. |
| 08 44 29 | P | Auto reentry. I see when each one of the thrusters fires, the little fireflies come out of the thrusters and drift away to the rear. Some of them impinging on the spacecraft but depart later. The auto reentry [ASCS reentry attitude mode] portion of the auto mode is holding within plus or minus—within a 11½ degree band. That is, is apears to be slightly more sloppy than ASCS orbit. However, this may not be true; ASCS orbit is not very fine control either. But it is controlling it fairly well. |

COASTAL SENTRY QUEBEC (SIXTH PASS)

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|---|---|---|
| 08 52 13 | P | . . . |
| 08 52 16 | CC | Roger. We're not getting T/M very good here. Do you have T/M on? Over. |
| 08 52 21 | P | Roger. |
| 08 52 22 | CC | Roger. He has T/M on. |
| 08 52 26 | CC | Do you have TV on, Gordo? Over. |
| 08 52 28 | P | Negative. |
| 08 52 30 | CC | Roger. |
| 08 52 31 | P | TV coming on now. |
| 08 52 33 | CC | Roger. |
| 08 52 37 | CC | Are you ready to copy retro times? Over. |
| 08 52 39 | P | Roger. Go. |
| 08 52 41 | CC | Roger. [Contingency recovery area] 7–A [retrosequence time] is 09+11+42 and 7–B is 09+40+19. Over. |
| 08 52 56 | P | Roger. . . . |
| 08 53 06 | CC | This is CSQ. I didn't get your readback on that. Over. |
| 08 53 30 | CC | Faith Seven, CSQ. Cape wants a cabin air temp readout, please. Over. |
| 08 54 00 | CC | This is CSQ, Faith Seven. We're reading you very weak, barely readable. Repeat cabin air temp please. Over. |
| 09 00 20 | P | Now I am getting ready to release the balloon. I have tape on continuous; I'm on fly-by-wire low, going to three zeros. Camera is in place in the mount and really is in the way of the yaw indicators. And I am on three zeros, squib switch to arm, 16 millimeter camera on, going to extend, hold for 5 seconds; 1, 2, 3, 4, 5, off. |
| 09 01 26 | P | Squib off. Pitching slowly down, very, very slowly, going down—very slowly. I did not hear the balloon deploy. Perhaps you cannot hear it deploy; I don't know. Easing down ever so slowly. And I don't see the balloon anywhere yet. And I'm doing a rather sloppy job of flying now, trying to look for the balloon. |

| | | |
|---|---|---|
| 09 04 21 | CC | Hello Faith, Faith Seven. Hawaii Cap Com. Do you read? |
| 09 04 23 | P | Roger. Faith Seven here. |
| 09 04 26 | CC | Roger. Gordo, reading you 3 by 3. We need a fuel, and oxygen and cabin-air temperature readouts please. |
| 09 04 34 | P | Roger. Cabin air, 90 [degrees]; fuel is 86 percent [auto]; 102 percent [manual]. Oxygen is 190 and 100 [percent]. |
| 09 04 46 | CC | Roger, copied. Are you ready to begin your balloon experiment at this time? Over. |
| 09 04 52 | P | I have already tried to deploy the balloon at 9 hours. The balloon did not deploy. |
| 09 05 01 | CC | Roger. Understand you tried to deploy the balloon at 9 hours elapsed, and it did not deploy. Is that correct? |
| 09 05 08 | P | This is affirm. |
| 09 05 11 | CC | Roger. Have you had any food and water yet? |
| 09 05 14 | P | Roger. I have had food and water. |
| 09 05 16 | CC | Roger. Would you care to comment on the ground-light experiment? |
| 09 05 20 | P | Roger. I saw the ground-light experiment. |
| 09 05 24 | P | *Would you ask Cape if they would like me to try deploying this balloon again? Over. |
| 09 05 30 | CC | Roger. They are monitoring you; you will get an answer from them shortly. What's your control mode, your gyro switch position, and your status? |
| 09 05 40 | P | Roger. My status is go, my control mode is fly-by-wire low; gyros are on slave. |
| 09 05 51 | CC | And your gyro switch position, please? |
| 09 05 54 | P | Gyro switch position is slave. Over. |
| 09 06 01 | CC | Roger. |
| 09 06 05 | CC | *Faith Seven, Hawaii Cap Com. Cape advises that you try to deploy the balloon again, and would you give us a mark when you throw the switch. Over. |
| 09 06 08 | P | Roger. |
| 09 06 17 | P | Roger. |
| 09 06 27 | P | Roger, 16-mm camera is on. |
| 09 06 33 | CC | Roger, Gordo. Is your squib switch on? |
| 09 06 35 | P | Not yet. It will be before I try again, though. |
| 09 06 38 | CC | Roger. Just give us a countdown. |
| 09 06 41 | P | Roger. Squib is coming on NOW. [09 06 44]$^{T}$ |
| 09 06 45 | CC | *Roger. Understand squib switch is on now. |
| 09 06 56 | P | 5, 4, 3, 2, 1 [09 07 05]$^{T}$—no joy. |
| 09 07 06 | CC | Roger. Understand the balloon still does not deploy. |
| 09 07 13 | P | Squib switch is off. |
| 09 07 16 | CC | Roger. Understand squib switch is off. Hawaii standing by. |
| 09 07 57 | CC | Faith Seven. Hawaii Cap Com. |
| 09 07 58 | P | Go ahead, Hawaii. |
| 09 07 59 | CC | Roger. What's your status with respect to cabin temp and suit temp? Do you feel hot? |
| 09 08 06 | P | Roger. Cabin temp is 90 [degrees], suit temp is 61 [degrees]. |
| 09 08 11 | CC | Okay. And you feel okay, not too hot? |
| 09 08 12 | P | Roger, feel fine. |
| 09 08 15 | CC | Sounds fine, you look fine. Have a good flight. |
| 09 08 17 | P | Roger, thank you. |
| 09 10 04 | P | *The balloon did not deploy; felt no shock; hear nothing on it. I will go continuous this portion where the balloon normally would have been used, in auto reentry. I will go around in auto orbit mode. Perhaps I can snap a few pictures for the ground people. |
| 09 11 18 | P | *. . . Bingo, I shifted into auto, orbit mode. I got no thrusters on the shift—and scanners seem to be holding it relatively close. |
| 09 18 40 | P | *What do you know? The Kenney Kleinknecht experiment is putting water in the exhaust tube, so maybe it is working here. |
| 09 21 31 | P | Short status report. . . . air outlet, 68 degrees. 250 inverter, 120 [degrees], 150 inverter, 128 [degrees], standby inverter, 102 [degrees]. Reserve peroxide tank, 71 [degrees]; manual peroxide tank, 69 [degrees]; auto peroxide tank, 78 [degrees]. [Retropack] is 61 [degrees]. Pitch down, 52 [degrees]; pitch up, 55 [degrees]. Yaw left, 68 [degrees]; yaw right, 68 [degrees]. Roll counterclockwise, 85 [degrees]; roll clockwise, 82 [degrees]. Regulated low nitrogen pressure, 475 [psi] auto; 490 [psi] manual. Isolated bus 28 volts. |

| | | |
|---|---|---|
| 09 27 08 | P | . . . going to pump the rest of that urine into the number 2 tank. First . . . sample. I believe it is pumping correctly. The thing about this pumping under zero g is not good, tends to stand in the pipes, and you have to actually forcibly force it through. |
| 09 40 20 | P | Radiation experiment on at 09 39. |
| 09 50 25 | P | Radiation experiment coming off, NOW. [09 50 29]$^{T}$ |

ZANZIBAR (SIXTH PASS)

| | | |
|---|---|---|
| 10 00 09 | P | . . . $O_2$ primary is 79 percent. |
| 10 00 18 | CC | Reconfirm that, please. |
| 10 00 19 | P | Roger. Just a hair short of 80 percent. Over. |
| 10 00 24 | CC | $O_2$ primary? |
| 10 00 27 | P | $O_2$ primary. That's coming in at 180 percent. Over. |
| 10 00 33 | CC | Affirmative. |
| 10 00 35 | P | It's that Frank Samonski gage, and the secondary is 100 percent. |
| 10 00 41 | CC | Affirmative. |
| 10 00 47 | CC | Faith Seven, this is Zanzibar Cap Com. At this time, you are go for 17 [passes]. You are go for 17. |
| 10 01 00 | P | Roger. Thank you, Zanzibar. |
| 10 01 04 | CC | MCC advises that they do not want you to jettison your balloon. They are working on an alternate method for releasing the balloon. |
| 10 01 17 | P | Roger. Understand. I will not jettison. |
| 10 01 20 | CC | Roger. |
| 10 01 29 | CC | Faith Seven, Zanzibar Cap Com. |
| 10 01 30 | P | Go ahead. |
| 10 01 31 | CC | I have new [retrosequence] times for [recovery area] 7–1. Are you ready to copy? |
| 10 01 35 | P | Roger. Go. |
| 10 01 37 | CC | Your G.m.t. or c.—, do you want G.m or c.? |
| 10 01 42 | P | C.e.t. |
| 10 01 47 | CC | C.e.t. is 10 23 37 c.e.t. Do you read? |
| 10 02 01 | P | Roger. 10 23 37. Understand. |
| 10 02 05 | CC | That takes into account the 5-second error in your clock. |
| 10 02 09 | P | Roger. Thank you. |
| 10 02 16 | CC | Faith Seven, Zanzibar Cap Com. Check your cabin [heat exchanger] dome temperature. |
| 10 02 23 | P | Roger. Cabin dome temperature is 70 degrees. |
| 10 02 28 | CC | We confirm on the ground. |
| 10 02 29 | P | Roger. |
| 10 02 39 | CC | Can you give us a $PO_2$ cabin? |
| 10 02 42 | P | Roger. $PO_2$ cabin is about 4.4 psi. |
| 10 02 51 | CC | 4.4? |
| 10 02 54 | P | Roger. |
| 10 03 31 | CC | Faith Seven, Zanzibar Cap Com. |
| 10 03 34 | P | Roger. Go. |
| 10 03 37 | CC | Everything looks good here. |
| 10 03 39 | P | Roger. Thank you very much. Everything looks good here. |
| 10 03 42 | CC | Okay, Zanzibar out. |
| 10 03 44 | P | Roger. |
| 10 04 07 | P | *Putting my visor back now. I've had to keep increasing the suit flow from a [comfort control valve] setting of 1.5 that I have right now to a setting of about 2.7. Dome is about 58 degrees. Inlet temp. is 58 degrees. This increase in the suit water flow is probably required by the cabin going on up. The heat load in the cabin is gradually going on up, using powered up, and having a cabin fan and cabin coolant turned off. |
| 10 18 23 | P | At a [comfort control valve] setting of 3 on the heat exchanger. |

COASTAL SENTRY QUEBEC (SEVENTH PASS)

| | | |
|---|---|---|
| 10 24 57 | CC | Hello, Faith Seven, CSQ Cap Com. Over. |
| 10 25 01 | P | Roger, John. Faith Seven here. |
| 10 25 03 | CC | Faith Seven, CSQ. Cape advises you could go ahead and power down here, over our site if you like. Over. |
| 10 25 11 | P | Roger. Will do. You have any kind of a reproduction device down there? |

| | | |
|---|---|---|
| 10 25 16 | CC | No, we're not, Gordo. We're not getting a doggone thing on that; don't know what's wrong with it. You are transmitting, is that affirm? |
| 10 25 23 | P | Roger. |
| 10 25 25 | CC | Nope. We're not getting any TV at the moment. |
| 10 25 28 | P | Okay. . . . |
| 10 25 39 | CC | Negative. The boys here tell me we're not getting any carrier on it at the moment. |
| 10 25 47 | P | Roger. |
| 10 25 59 | CC | This is CSQ Cap Com. You're going ahead and powering down, is that affirmative? |
| 10 26 07 | P | That is affirm. I'm going to fly-by-wire now. . . . |
| 10 26 10 | CC | Roger. |
| 10 26 21 | P | Roger. Auto is off. |
| 10 26 24 | CC | Roger. Auto off. |
| 10 26 32 | P | Gyros are caged. |
| 10 26 34 | CC | Roger. Gyros caged. |
| 10 26 40 | P | ASCS a-c bus off. |
| 10 26 43 | CC | Roger. |
| 10 26 54 | P | The highest my 250 inverter got up to was 130 degrees. |
| 10 26 59 | CC | Roger. Understand 250 only got up to 130, is that affirm? |
| 10 27 03 | P | Roger. |
| 10 27 30 | CC | Roger. We're dropping you. |
| 10 27 40 | CC | Gordo, the surgeon wants to know if you're sweating any at the moment. Over. |
| 10 27 46 | P | Very lightly, not very much. |
| 10 27 49 | CC | Roger. |
| Unreadable | P | *. . . At roughly 10 hours and 27 minutes, brought auto ASCS control to select. Lights are off. Caged the gyros. Have ASCS a-c bus. At the time the 250 inverter was reading 130 degrees, the highest it had been. The cabin was 96 degrees, the highest it has been. The cabin already is coming down; it's 91 degrees, already. |

## HAWAII (SEVENTH PASS)

| | | |
|---|---|---|
| 10 37 27 | CC | Hello Faith Seven, Hawaii Cap Com. Do you read? |
| 10 37 45 | CC | Faith Seven, Hawaii Cap Com. How do you read? |
| 10 37 52 | P | . . . |
| 10 37 55 | CC | Roger, Faith Seven. Reading you 3 by 4. Will you turn your tape recorder to program at this time. |
| 10 38 05 | P | Roger. It is on program. Over. |
| 10 38 08 | CC | Roger. R and Z cal to auto. |
| 10 38 12 | P | R and Z cal is in auto. |
| 10 38 13 | CC | And C-band beacon to ground command now. |
| 10 38 17 | P | C-band to ground command now. |
| 10 38 19 | CC | Roger. We're standing by for a blood pressure and a fuel and oxygen readout. |
| 10 38 24 | P | Roger. Fuel, 81 [percent] auto, 101 [percent] manual. Oxygen is 175 percent primary, 100 percent secondary. Cabin temp, 90 degrees. Here comes blood pressure. |
| 10 38 44 | CC | Roger. Understand blood pressure is on the air. Say again cabin temp. |
| 10 38 48 | P | Cabin temp is 90 degrees. |
| 10 38 51 | CC | Roger. Read 90. |
| 10 39 12 | CC | Faith Seven, Hawaii Cap Com. Turn your C-band beacon on at this time. Over. |
| 10 39 18 | P | Roger. Coming on now. |
| Unreadable | CC | Roger, your [contingency recovery area] 8-Alpha and 8–Bravo [retrosequence] times are nominal. |
| 10 39 25 | P | Roger. 8-Alpha and Bravo are nominal. |
| 10 39 30 | CC | T/M is commanded. Stand by. |
| Unreadable | CC | Roger, Faith Seven, Hawaii Cap Com. Commanding T/M on at this time. |
| 10 39 56 | P | I have it on continuous. You want it on ground command? |
| 10 39 59 | CC | Negative, that's fine. |
| 10 40 05 | P | Okay. |
| 10 40 18 | CC | Faith Seven, Hawaii Cap Com. Turn your T/M to ground command. |
| 10 40 23 | P | Roger. Going to ground command now. |
| 10 40 29 | P | On ground command. |
| 10 40 35 | CC | Roger. |

| | | |
|---|---|---|
| 10 41 03 | ? | . . . Cooper, can you come in on emergency frequency. Come up on 11176. Hickam out. |
| 10 41 35 | CC | Faith Seven, Hawaii Cap Com. Your mode and gyro switch position please. |
| 10 41 40 | P | Roger. Roger. ASCS control on select, mode select off, fly-by-wire thrust select low, pitch torquing on, gyros to cage, and pitch attitude on orbit. |
| 10 41 53 | CC | Hawaii. Roger. |
| 10 42 29 | CC | T/M commanded on this time. Faith Seven. |
| 10 42 33 | P | Roger. |
| 10 43 14 | CC | Faith Seven, Hawaii Cap Com. We're receiving R cal at this time. Will you make sure you have your C-band beacon to ground command before AOS. Over. |
| 10 43 24 | P | Roger, will do. |
| 10 43 41 | P | C-band beacon coming to ground command now. |
| 10 43 44 | CC | Roger. Understand C-band, ground command now. |
| 10 49 34 | P | Took some pictures out of the window with the remainder of the first roll of film on the 16 mm. The color film camera in the bracket. |
| 10 50 18 | P | * Low nitrogen pressure in 475 [psi] auto; 490 [psi] manual. B-nut temps: pitch down, 86 [degrees]; pitch up, 65 [degrees]; yaw left, 66 [degrees]; yaw right, 70 [degrees]; roll counterclockwise, 98 [degrees]; roll clockwise, 92 [degrees]. Auto peroxide tank, 82 [degrees]; manual peroxide tank, 68 [degrees]; reserve peroxide tank, 76 [degrees]. |
| 10 51 18 | P | Isolated bus, 28 volts, and I am pulling 6 amps, right now. |
| 11 16 18 | P | Tape [and radiation] experiment is now on. I'm eating a pot roast or beef. I've had considerable difficulty getting the water in it from this water device on the McDonnell water tank. I spilled water all over my hands and all over the cockpit here trying to get some in it. I have succeeded in getting about half of it dampened and am proceeding to eat. |
| 11 19 20 | P | I am washing my face with a damp cloth now. Certainly feels good. |
| 11 22 30 | P | [Forcing grunt]. This is ridiculous. Come out of that damned ditty bag—Pandora's locker. |
| 11 28 31 | P | Radiation experiment is off. Tape recorder to program. |
| 11 31 00 | P | * It is rather a strange feeling to be able to place objects out into the cabin and let go of them and they'll stay in relatively their same position. This is worrisome as well as an odd sensation. Handy sometimes. |

ZANZIBAR (EIGHTH PASS)

| | | |
|---|---|---|
| 11 33 07 | CC | Faith Seven, Zanzibar Cap Com. I'd like to get a c.e.t. time hack in about 30 seconds. |
| 11 33 15 | P | Roger. We have 11 34 30 on my mark. 5, 4, 3, 2, 1, MARK. [11 33 31]$^{T}$ |
| 11 33 36 | P | That's 11 33 30. |
| 11 33 38 | CC | Roger. |
| 11 33 49 | CC | Faith Seven, Zanzibar Cap Com. |
| 11 33 53 | P | Go ahead. |
| 11 33 54 | CC | Your clock is now 7 seconds fast—plus 7 seconds. |
| 11 34 01 | P | Roger. Understand. Plus 7 seconds. |
| 11 34 06 | CC | [Recovery area] 9–1 [retrosequence] time is 13 19 20. 13 19 20. |
| 11 34 21 | P | Roger. 13 19 20. |
| 11 34 25 | CC | If you have to set your clock, you'll have to add 7 seconds to that. |
| 11 34 30 | P | Roger. Understand. |
| 11 34 40 | CC | Your T/M looks good on the ground, Faith Seven. Your T/M looks good. |
| 11 34 45 | P | Roger. Thank you. |
| 11 34 49 | CC | We'd like to have a TRF clock readout from the capsule also, please. |
| 11 34 54 | P | Roger. Time to retrograde will be 22 23 20 on my mark. MARK. [11 35 07]$^{T}$ Retrograde time, 33 58 26. |
| 11 35 15 | CC | We concur. |
| 11 35 17 | P | Roger. |
| 11 35 57 | CC | Faith Seven, Zanzibar Cap Com. |
| 11 36 01 | P | Go ahead. |
| 11 36 03 | CC | Everything looks real good on the ground. Cape says they have nothing else for you at this time. We'll see you next time around. |
| 11 36 09 | P | Roger, Zanzibar. Thank you. |

| | | |
|---|---|---|
| 11 49 58 | P | * All right on number 2 [photograph]. I've just taken [a picture, number 3] over India. And I'm just coming in over China very shortly. This is on the general purpose film in the Hasselblad. |
| 11 51 21 | P | *Photo 3 with the general purpose film. Here come the Himalayas. Number 4 [photograph] of the Himalayas. First three at 1/250, f/11. These are two . . . that last one was 1/250, f/16. |

COASTAL SENTRY QUEBEC (EIGHTH PASS)

| | | |
|---|---|---|
| Unreadable | CC | Faith Seven. |
| Unreadable | CC | Hello, Faith Seven CSQ Cap Com. Over. |
| 11 55 57 | P | Roger. Faith Seven here. |
| 11 55 58 | CC | Roger. Reading you loud and clear, Gordo. Is the TV on? |
| Unreadable | P | Negative. I'll bring it on now. I didn't think it would work. |
| Unreadable | CC | Roger, go ahead. We didn't pick it up before here. I got your [contingency recovery area] 9-Able and Baker [retrosequence] times for you if you're ready for them. |
| 11 56 13 | P | Roger, stand by 1. Roger, go. |
| 11 56 39 | CC | Roger. 9–A is 12+18+24 and 9–B is 12+43+05. Over. |
| Unreadable | P | Roger 12 18 24. 12 43 05. |
| Unreadable | CC | That's affirmative, and Cape requests at the end of this pass you can turn your R and Z cal switch off so it will be off for the rest period. Over. |
| Unreadable | P | Roger. |
| 11 56 57 | CC | There we go. We're getting a little picture on you here now, if we can get the thing adjusted a little better. |
| 11 57 07 | P | Roger. How's that? |
| 11 57 10 | CC | We're receiving a carrier on you here but we're not getting very good modulation. Just big light spots going on and off. Over. |
| 11 57 18 | P | Roger. Probably not getting too much light. Just 1 second—I should be getting enough Earth shine off of it here to help. |
| 11 57 25 | CC | Okay, good. You upside down? |
| 11 57 27 | P | Roger. |
| 11 57 37 | CC | Is it on you? |
| 11 57 39 | P | Roger. |
| 11 57 46 | CC | Can you open the lens up a little bit on that. It's not getting enough light here. |
| 11 57 50 | P | Okay it's wide open now. |
| 11 57 51 | CC | Roger. |
| 11 58 49 | CC | You on fly-by-wire, Gordo? |
| 11 58 52 | P | Negative. I have everything powered down now. |
| 11 58 56 | CC | Roger. Just drifting. Affirm? |
| 11 58 57 | P | Roger. |
| 11 58 58 | CC | Roger. |
| 11 59 04 | P | Full drift with ASCS a-c powered down. |
| 11 59 07 | CC | Roger. |
| 11 59 38 | CC | You're sure looking good. Everything couldn't be finer on this pass. |
| 11 59 43 | P | Roger. Everything looks good here, John. |
| 12 00 09 | CC | How's cloud cover? Do you have a pretty good view? |
| 12 00 14 | P | Quite a bit of cloud cover right over you here. A little bit earlier there was a pretty good open area. |
| 12 00 23 | CC | It should be interesting to look at. |
| 12 00 26 | P | Roger. |
| 12 01 07 | CC | For your info, Gordo, we're getting good reports from the monitor aircraft for later on, for retro too. |
| 12 01 13 | P | Roger. Thank you. |
| 12 01 30 | CC | Surgeon would like to know what your cabin temp is now. |
| 12 01 33 | P | Roger. Cabin temp is about 87 degrees. |
| 12 01 37 | CC | Roger, very good. You're looking fine. |
| 12 05 58 | P | *An interesting aspect of this little liquid experiment that I have along is that the liquid remains on it in globules, hanging along the side in round globule form; and the air is trapped within it in globules and does not separate from it. |

## HAWAII (EIGHTH PASS)

| | | |
|---|---|---|
| 12 11 40 | CC | Faith Seven, Hawaii. Do you read? |
| 12 11 46 | P | Roger, Hawaii. Faith Seven reading you loud and clear. |
| 12 11 48 | CC | Roger. Reading you loud and clear. Standing by for blood pressure, fuel and oxygen. |
| 12 11 52 | P | Roger. |
| 12 12 01 | P | Blood pressure coming now. |
| 12 12 03 | CC | Roger. |
| 12 12 09 | P | Fuel is 81 percent auto; 101 percent manual. Oxygen is just about 170 percent primary, and 100 percent secondary. |
| 12 12 30 | CC | Roger, Faith Seven. Say again oxygen secondary. |
| 12 12 33 | P | 100 percent. |
| 12 12 35 | CC | 100, roger. Blood pressure off at this time, please. And did you say 101 manual fuel? |
| 12 12 46 | P | That's affirmative 101 manual and about 81 automatic. |
| 12 12 51 | CC | Roger. That's all we need. You look good on the ground, you're doing a great job. |
| 12 12 57 | P | Roger, thank you, Buddy. |
| 12 13 24 | CC | Faith Seven, Hawaii. You clock is holding 7-second error. |
| 12 13 28 | P | Roger. Thank you. |
| 12 14 08 | P | The eighth picture was shot over Hawaii to the south. |
| 12 14 17 | CC | Faith Seven, Hawaii. Could you give me suit [heat exchanger] dome temp, please. |
| 12 14 21 | P | *Roger. Suit dome temp is about 45 degrees. I increased flow. Got it down a little low, and I'm easing it back now. |
| 12 14 31 | CC | Roger. Understand, understand suit dome 45. |
| 12 14 35 | P | *That's right. |
| 12 14 48 | CC | Faith Seven, Hawaii. What about $O_2$ partial pressure. |
| 12 14 53 | P | Roger. $O_2$ partial pressure is about 4.2 [psi], cabin. |
| 12 14 57 | CC | 4.2. Roger. |
| 12 14 58 | P | Roger. |
| 12 15 18 | P | Roger. Now back to the scribe mark on the suit temperature selector of about 2.7 with the power down. |
| 12 15 31 | CC | Faith Seven, Hawaii. Our T/M shows suit dome of about 38 degrees. |
| 12 15 41 | P | Roger. I just decreased the setting, just a minute ago, again. |
| 12 15 45 | CC | Roger. |
| 12 17 33 | P | *Suit dome temp.'s down to about—slightly below 40 degrees. Decreased the setting of the flow twice, and it's on its—should be on its way back up any moment. |
| 12 21 36 | P | *Short status report: Hydrogen peroxide and low nitrogen pressure: 475 [psi] auto, 490 [psi] manual. B-nut temps: pitch down, 85 [degrees]; pitch up, 60 [degrees]; yaw left, 55 [degrees]; yaw right, 70 [degrees]; roll counterclockwise, 85 [degrees]; clockwise, 92 [degrees] . . . auto tank, 85 [percent]; manual tank, 68 [percent]; reserve tank, 98 [percent]. Isolated bus voltage, 28 [volts]. Pumping from the condensate tank to the reserve tank, I have a syringe full. Suit circuit seems to be getting varying amounts of water, probably from the condensate tank, or tin can. Coolant water flow seems to vary considerably. I have it clear back down to a setting of 1. Still haven't gotten the heat exchanger dome temperature out of the warning light area. It is now about 45 degrees. Never have been able to put water in these containers, that have water, due to the leaking of this valve in the back of it. I'm unable to put it into the water, into the plastic neck of the container, and get water into it without leaking water all over the cockpit. |

## ROSE KNOT VICTOR (EIGHTH PASS)

| | | |
|---|---|---|
| 12 26 00 | CC | Faith Seven, RKV Cap Com. |
| 12 26 05 | P | Hello RKV. |
| 12 26 07 | CC | We have aeromed and systems go here. |
| 12 26 18 | P | Roger. Say again RKV. |
| 12 26 21 | CC | We have aeromed go here, and systems go. |
| 12 26 25 | P | Roger, very good. I'll take the temperature probe out now, then. |
| 12 26 30 | CC | We've got a long list of capsule readouts that the Cape requires before you go into the |
| 12 26 42 | P | rest period. |
| 12 26 43 | CC | Roger. Go. |

| | | |
|---|---|---|
| 12 26 53 | P | Okay, 24 volts main. Just rotate the switch through, Gordo. All positions on your d-c volts. Roger, d-c volts: Main [bus], 24½ [volts], isolated [bus], 28 [volts]; main [battery] one is 25 [volts]; main [battery] two is 25 [volts]; main [battery] three is 25 [volts]; standby [battery] one is 25 [volts]; standby [battery] two is 25 [volts]; isolated [battery], 28½ [volts]. |
| 12 27 11 | CC | Roger, understand. 150 v-a [inverter] volts? |
| 12 27 17 | P | Roger, 150 v-a is still 121 [volts]; fan, 121 [volts]. |
| 12 27 24 | CC | Fans bus, 121 [volts]? |
| 12 27 26 | P | Roger. |
| 12 27 27 | CC | Suit-coolant and cabin-coolant control valve settings. |
| 12 27 33 | P | Roger. I'm back on 2.5 on the suit. Cabin is still shut down. |
| 12 27 41 | CC | Roger. Partial $CO_2$ and partial $O_2$. |
| 12 27 45 | P | Roger. Partial $O_2$ cabin is about 4.2 [psi], and suit $CO_2$ is on the bottom peg, zero. |
| 12 27 55 | CC | Roger. Auto and manual fuel pressure? |
| 12 27 59 | P | Roger. Auto fuel pressure, 475 [psi]; manual fuel pressure 490 [psi]. |
| 12 28 04 | CC | Roger. Okay temperatures, just rotated through pitch, and all the way through. |
| 12 28 13 | P | Roger. Retro, 62 [degrees]. Pitch down, 75 [degrees]; pitch up, 60 [degrees]. Yaw left, 55 [degrees]; yaw right, 70 [degrees]. Roll counterclockwise, 95 [degrees]; roll clockwise, 93 [degrees]. |
| 12 28 37 | CC | Roger, $H_2O_2$ reserve, manual and auto. |
| 12 28 41 | P | Roger. Auto peroxide tank is 85 [degrees], manual is 68 [degrees], and reserve is 78 [degrees]. |
| 12 28 52 | CC | Roger. Cabin heat-exchanger-outlet temperature. |
| 12 28 55 | P | Cabin heat-exchanger outlet 72 [degrees]; 250 inverter, 112 [volts]; 150 inverter, about 1—just a second I'll get a light on, I'm getting in the dark—125 [volts]. |
| 12 29 13 | CC | Roger. |
| 12 29 14 | P | Fans inverter about 110 [volts]. |
| 12 29 17 | CC | Roger. |
| 12 29 23 | CC | Okay, that settles this. Can you give me some indication of your tape remaining? |
| 12 29 29 | P | Roger. Just a moment. Roger. I have about 75 percent remaining. |
| 12 29 44 | CC | Roger. Can you give us a blood pressure? |
| 12 29 50 | P | Roger. Coming now. |
| 12 29 56 | CC | Okay, the Cape advises that if you desire to turn your T/M to continuous, we'll cut down on the unnecessary communications for the rest of the rest period. |
| 12 30 11 | P | Roger. |
| 12 30 31 | CC | C.e.t. is showing plus 7, plus 7. |
| 12 30 35 | P | Roger. Plus 7. |
| 12 31 12 | CC | Seven, RKV. Do you intend to go on a rest period from this site? |
| 12 31 17 | P | Roger. |
| 12 31 46 | CC | Seven, RKV. Are you sweating any? |
| 12 31 50 | P | Negative. |
| 12 31 52 | CC | No sweat. |
| 12 32 08 | CC | We have you all go on aeromedical and systems. Looks like you can settle down for a long rest. |
| 12 32 14 | P | Roger. Thank you. |
| 12 32 36 | CC | Seven, RKV. We have LOS. |

(NINTH PASS)

| | | |
|---|---|---|
| 13 17 17 | P | Photo number 8 being made over Africa, to the north. *(Non-flight-related transmission omitted.) |
| 13 18 47 | P | Another being made over Africa. |
| 13 20 32 | P | I can see roads, and rivers, and some small towns down here on the ground. Small villages are pronounced. Can almost make out the individual houses. |
| 13 23 30 | P | *Now we're in the next series of 12. Over . . . Africa. The first series were started over Africa and across on orbit 9—on across Arabia through India, and that last series of three or four pictures were made right over the Himalayas, and in the India, India-China area. |
| 13 28 39 | P | Checking fly-by-wire thrusters, they all work. Fly-by-wire lows, manual proportional, and checking manual thrusters now. Checking yaw, and yaw works, pitch down works, pitch up works, roll left works, roll right works. Manual handle off. |

| | | |
|---|---|---|
| 13 32 41 | P | CSQ Cap Com. Faith Seven. |
| 13 33 18 | CC | Hello, Faith Seven, CSQ. Roger. Received you, go ahead with your message. |
| 13 33 24 | P | Roger. Just passing over. Everything's nominal here I haven't really started my rest period yet. I had a little tussle with the heat exchanger, with the suit, and I finally got it adjusted. |
| 13 33 38 | CC | Roger. Understand, heat exchanger is adjusted now for suit. We are still trying to pick up your TV here. We're not getting a very good picture on it. Over. |
| 13 33 46 | P | Roger. |
| 13 33 48 | CC | Roger. We had a message out around the range here to keep quiet that you were asleep, and we thought it looked like a typical asleep-type pass on your biosensors here. |
| 13 33 59 | P | Roger. |
| 13 34 02 | P | Roger. I was busy here just before the pass. |
| 13 34 04 | CC | Roger. |
| 13 34 10 | CC | Did you say you were asleep just before the pass. Over. |
| 13 34 13 | P | Negative. I was busy looking out the window and fiddling with this suit dome temp. |
| 13 34 20 | CC | Roger. |
| 13 34 28 | P | I've checked my manual and fly-by-wire thrusters and am ready to start my rest period now. |
| 13 34 35 | CC | Roger. Understand checked manual fly-by-wire. Ready to start rest period now. |
| 13 34 39 | P | Roger. |
| 13 34 42 | CC | All right. You will tell everyone to go away and leave you alone now. Okay? |
| 13 34 48 | P | Roger. |
| 13 34 52 | CC | You're looking real good, Gordo. Everything is going real fine, boy. |
| 13 34 55 | P | Roger. Thank you, John. |
| Unreadable | P | *. . . fourth picture on that second series was made just out from CSQ. Number 6 of second series, taken over at 13 56. Went to sleep at about 13 50. Slept 'til 14 46 quite soundly, slept quite heavily, awoke not realizing where I was—completely, soundly asleep. Picture 8 of second series in the Burma-India area at 14 58 30. Took number 9 over the Himalayas. |

TENTH PASS

| | | |
|---|---|---|
| 15 11 35 | P | *Standby inverter, 102 [degrees]; 150 inverter, 110 [degrees]; 250 inverter, 102 [degrees]; $H_2O_2$ auto tank, 85 [degrees]; manual fuel tank, 70 [degrees]. Roll counterclockwise, 78 [degrees]; roll clockwise, 82 [degrees]; yaw right, 65 [degrees]; yaw left, 64 [degrees], pitch up, 58 [degrees]; pitch down, 70 [degrees]. Retro, 67 [degrees]. I put the window cover on 15 14 15 for a period of time and now have awakened. |

ELEVENTH PASS

| | | |
|---|---|---|
| 16 28 51 | P | *Short status report: Peroxide low pressure regulated: 475 [psi] auto; 490 [psi], manual; clockwise thruster, 72 [degrees]; counterclockwise thruster, 78 [degrees]. Yaw right at 61 [degrees]; yaw left at 60 [degrees]; pitch up is 52 [degrees], pitch down is 58 [degrees]. Retro is 55 [degrees]; auto 85 [degrees]; manual is 70 [degrees]; . . . reserve is 70 [degrees]. Photo series at 16 hours and 40 minutes. Having the problem with the suit exchanger dome temp, . . . down to the freezing mark with a [comfort-control-valve] setting of about 1½. Take a setting of 1 to 1½ and then takes almost turning it off to get it back. It seems to be very inconsistent, in the settings that will take to hold an even heat exchanger dome temperature. Went asleep again and am awake now. Suit temperature is . . . 5. |

TWELFTH PASS

| | | |
|---|---|---|
| 18 04 20 | P | Photo sequence number 3 made on the Indian coast line at 18 hours and 4 minutes. Next photo made at 18 hours and 5 minutes. |
| 18 14 01 | P | *The time is now 18 hours and 14 minutes. Short status report: Nitrogen low pressures: 475 [psi], auto; 490 [psi], manual. Retropack, 71 [degrees]. Pitch down thruster, 58 [degrees]; pitch up, 50 [degrees]. Yaw left, 58 [degrees]; yaw right 52 [degrees]; roll counterclockwise, 72 [degrees]; [roll] clockwise, 70 [degrees]. $H_2O_2$ auto tank, 82 [degrees]; peroxide manual tank, 72 [degrees]; peroxide reserve. . . . Main bus is 25½ [volts]; isolated bus voltage is 28½ [volts]. [Battery number 1] 25 [volts]; number 2 is 25 [volts]; number 3 is 25 [volts]; standby 1 is 25 [volts]; standby 2 is 25 [volts]; isolated is 28½ [volts]; back to main. Reading 121 volts on the fans. Everything is proceeding along very well. Everything is normal, except for this bothersome heat-exchanger dome temp, and I just can't seem to keep it either from being on the freezing mark or going on over. I vary the settings between . . . and completely off. |

| | | |
|---|---|---|
| 19 38 39 | P | *Went to sleep again, slept very soundly. And it's time for a short status report: Nitrogen regulated pressure . . . auto, 475 [psi], manual, 490 [psi]. B-nut temps: First, retro temp, 75 degrees. Pitch down thruster, 55 [degrees]; pitch up thruster, 50 [degrees] yaw left, 56 [degrees]; yaw right, 50 [degrees]; Roll counterclockwise, 72 [degrees]. Roll clockwise, 70 [degrees]; Peroxide auto tank, 82 [degrees]; manual tank, 72 [degrees]; reserve tank, 75 [degrees]. Isolated bus voltage, 28. |
| 19 42 15 | P | *One comment on these various sleep periods that I've had; nearly everytime that I have awakened, I found that I have been so soundly asleep I don't even know where I am when I awake. |
| 20 23 37 | P | *Have a note to be added in for head-shrinkers. Enjoy the full drifting flights most of all, where you have really the feeling of freedom, and you aren't worried about the systems fouling up. You have everything turned off and just drifting along lazily. However, I haven't encountered any of this so called split-off phenomena. Still, note that I am thinking very much about returning to earth at the proper time and safely. Over. |

FOURTEENTH PASS

| | | |
|---|---|---|
| 21 00 35 | P | Time for another short status report. Auto regulated pressure: 475 [psi], manual, 490 [psi]. Retropack temp, 75 [degrees], pitch down thruster, 51 [degrees]; pitch up, 49 [degrees]; yaw left, 55 [degrees]; yaw right, 50 [degrees]; roll counterclockwise, 72 [degrees]; roll clockwise, 70 [degrees]. Peroxide auto tank, 80 [degrees]; manual tank, 74 [degrees]; reserve tank, 74 [degrees]. |
| 21 02 39 | P | Darned suit heat-exchanger [comfort-control valve] again. Setting is down to 1¼. One and one-half held it for a while. And now it's gone down to 40 [degrees] on the dome temp. Inlet temp, 62 [degrees]. |
| 21 05 16 | P | Number 7, sequence 3 was made looking back at Arabia. At 21 05, cabin temp is now 82 degrees; 250 inverter is 95 [degrees]; 150 inverter is 115 [degrees]; a standby inverter is 95 [degrees]. |

MUCHEA (FOURTEENTH PASS)

[Extended garbled transmission here. It sounded as though it might have been Spanish.]

| | | |
|---|---|---|
| 21 22 34 | P | Hello, Muchea Cap Com. Faith Seven here. Over. |
| 21 22 39 | CC | Go ahead, Faith Seven. This is Muchea Cap. |
| 21 22 43 | CC | Go ahead, Faith Seven. This is Muchea Cap Com. |
| 21 22 46 | P | Roger, Muchea Cap Com. Faith Seven. I'm awake now. Just thought I'd check in with you. |
| 21 22 50 | CC | Roger. How was your sleep? |
| 21 22 54 | CC | How was your sleep? |
| 21 22 56 | P | Very good. |
| 21 22 58 | CC | Do you like your coffee white or black? |
| 21 23 02 | P | I'll have tea, thank you. |
| 21 23 04 | CC | *Roger. |
| 21 23 10 | P | In fact, hot black tea would go very well right now. |
| 21 23 14 | CC | Roger. |
| 21 23 18 | CC | When you get a chance, will you give us your spacecraft status and your status? |
| 21 23 24 | P | Roger. Everything is nominal heare. I've had some difficulty with the suit heat-exchanger dome temp, and it's been running with the light on most of the time; but I have it well under control and the suit inlet temp has been running very comfortably. |
| 21 23 45 | CC | Very good. |
| 21 23 47 | P | My status is excellent. |
| 21 23 50 | CC | Roger. Will you give me an auto and manual fuel reading? |
| 21 23 55 | P | Roger. Let me get some more lights on here, since I'm in the dark. |
| 21 24 00 | P | *Roger. Auto fuel is reading 69 percent and manual 95 percent. |
| 21 24 10 | CC | Say again last. |
| 21 24 11 | P | Oxygen 150 percent on primary; 100 percent on secondary. The manual fuel is 95 percent. |
| 21 24 23 | CC | Roger. I didn't copy your manual fuel. |
| 21 24 25 | P | Roger. Manual fuel is 95 percent. |
| 21 24 28 | CC | I copied auto at 79. |
| 21 24 32 | P | Roger. It's 69, 69. |
| 21 24 35 | CC | Roger. |

| | | |
|---|---|---|
| 21 24 37 | P | Cabin temp is 84 degrees. |
| 21 24 41 | CC | Roger. |
| 21 24 55 | CC | Stand by, Faith Seven. |
| 21 24 57 | P | Roger. |
| 21 25 13 | CC | I have [recovery] area 15–1 retrosequence time. Please prepare to copy. |
| 21 25 21 | P | Roger. Go. |
| 21 25 24 | CC | 22 02 13. |
| 21 25 28 | P | Roger. 22 02 13. |
| 21 25 31 | CC | That's affirmative. Area 15–1. |
| 21 25 43 | P | Roger. Got it. |
| 21 25 45 | CC | What's your present control mode? |
| 21 25 49 | P | I'm in full drift. |
| 21 25 51 | CC | Roger. |
| 21 25 59 | CC | We have about 1 minute to LOS. |
| 21 26 02 | P | Roger. |
| 21 26 39 | CC | Hello, Faith Seven, Muchea Cap Com. Do you have anything to report? |
| 21 26 44 | P | Negative. I guess not. Everything's fine here. |
| 21 26 47 | CC | Roger. Systems report, you go here and aeromed, also. |
| 21 26 51 | P | Roger. Thank you. |
| 21 26 53 | CC | Roger. |
| 21 36 40 | P | *It is 21 36 46 NOW. (21 36 46)[T] I am observing lights of several small cities and scattered areas on the ground. Apparently over the east coast of Australia. |
| 21 46 18 | P | *I am viewing to the east now; and I can see very clearly, as I mentioned before, a band of haze layer above the Earth's horizon through which the stars can be seen. Although they're quite faint here and then clear below it. It goes around the earth, approximately the same distance around, just a corona-type thing around the Earth's surface. |
| 21 49 38 | P | *I would like to take this time to say a little prayer for all the people, including myself, involved in this launch and this operation. Father, thank You, for the success we have had in flying this flight. Thank You for the privilege of being able to be in this position, to be up in this wondrous place, seeing all these many startling, wondrous things that You've created. Help guide and direct all of us that we may shape our lives to be good, that we may be much better Christians, learn to help one another, to work with one another, rather than to fight. Help us to complete this mission successfully. Help us in our future space endeavors that we may show the world that a democracy really can compete, and still is able to do things in a big way, is able to do research, development, and can conduct various scientific, very technical programs in a completely peaceful environment. Be with all our families. Give them guidance and encouragement, and let them know that everything will be okay. We ask in Thy name. Amen. |

CAPE CANAVERAL (FIFTEENTH PASS)

| | | |
|---|---|---|
| 22 03 39 | P | Hello, Cape Cap Com. Faith Seven here. |
| 22 03 47 | P | Roger, shoot. |
| 22 03 55 | CC | The regulated low pressure scores. |
| 22 04 00 | P | Roger. I'm reading 475 [psi] auto and 490 [psi] manual. |
| 22 04 10 | CC | Could we have an $H_2O_2$ reading? |
| 22 04 16 | P | Roger. That's—say again. |
| 22 04 21 | CC | . . . . |
| 22 04 28 | P | Just a minute on the . . . . |
| Unreadable | P | Roger. |
| Unreadable | CC | Faith, can I have you on $H_2O_2$ tank temperature? |
| Unreadable | P | Auto tank is 81 degrees; manual tank is 74 degrees; reserve tank is 74 degrees. |
| 22 06 05 | CC | Faith Seven, Cape Cap Com. Over. |
| 22 06 07 | P | Cape, Faith Seven. |
| 22 06 09 | CC | Roger. Did you use any auto fuel during the sleep period? |
| 22 06 15 | P | Negative.[1] |
| 22 06 19 | CC | Would you put your R and Z cal to auto? |
| 22 06 22 | P | Roger. |
| 22 06 26 | CC | We reckoned your fuel to the 69 and 89 (percent). Over. |
| 22 06 32 | P | Roger. I read you 69 and 95. |

[1] *Pilot answer referred to current rest period only.*

| | | |
|---|---|---|
| 22 06 38 | CC | Roger. |
| 22 06 42 | CC | Is your tape recorder on schedule? |
| 22 06 57 | CC | We are getting a good picture of you on TV now. Over. |
| 22 07 01 | P | Roger. Understand. |
| 22 07 04 | CC | Did you transfer any water or urine? Over. |
| 22 07 10 | P | Boy, did I ever! |
| 22 07 17 | CC | Do you have any air wick observation? |
| 22 07 27 | P | Roger. They seem to separate water all right. |
| 22 07 39 | CC | Faith Seven, did you make any air wick observation? Over. |
| 22 07 43 | P | Affirmative. It does separate water. Over. |
| Unreadable | P | Did you read me, Cape? |
| Unreadable | CC | Roger. I read you now. Did you make an air wick observation? |
| 22 08 00 | P | Affirmative. It works. |
| 22 08 04 | CC | Roger. How is your comfort and humidity level in the suit? |
| 22 08 11 | P | Fine. |
| 22 08 12 | CC | Very good. |
| 22 08 15 | CC | Our surgeon has some goodies. Did you have any dreams? |
| 22 08 20 | P | Negative. I slept too soundly to dream. |
| 22 08 24 | CC | Roger. We thought you might have had one one time when your suit dome light may have come on. |
| 22 08 33 | P | My suit dome light was on a good portion of the time. |
| 22 08 36 | CC | Roger. We understand that. |
| 22 08 40 | CC | We'd like you to give a body temperature to Canary on your next pass over them coming up. Would you set your oral probe on for that? Over. |
| 22 08 50 | P | Roger. |
| 22 08 53 | CC | Pass time at Canary is nominal, so about 2 or 3 minutes before would help. |
| 22 09 00 | P | Roger. |
| 22 09 09 | CC | Would you give us a reading on your coolant-control-valve settings, and what they are now? |
| 22 09 16 | P | Roger. Right at the moment I'm reading about 1.8 on suit temp and the cabin is still turned off. |
| 22 09 27 | CC | Roger. We concur. |
| 22 09 45 | CC | Faith Seven. R and Z cal program switch to off. |
| 22 09 54 | P | Roger. Off. |
| 22 09 56 | CC | And you can secure TV. We had a pretty fair picture. |
| 22 10 00 | P | Roger. |
| 22 10 08 | CC | We can see you were drifting and dreaming, can't we? |
| 22 10 11 | P | Roger. |
| 22 10 30 | CC | Faith Seven, Cape Cap Com. |
| 22 10 32 | P | Come in Cape Com, Faith Seven. |
| 22 10 34 | CC | I've been asked to relay a message to you from the president of the Republic of El Salvador. I will read: "In the name of the Salvadorian government and people, and in my own right, it gives me pleasure to send you cordial greetings and sincere congratulations on the occasion of your valiant exploit, which constitutes an historic triumph for the free world. Julio Adalberto Rivera, President, El Salvador." |
| 22 11 06 | P | Very good, very good. |
| 22 11 07 | CC | Roger. |
| 22 12 00 | CC | Faith Seven, Cape Cap Com. |
| 22 12 02 | P | Go ahead, Cape. |
| 22 12 06 | CC | I'll give you c.e.t. hack at 50 mark. |
| 22 12 08 | P | Roger. |
| 22 12 09 | CC | That was 22 11 50. |
| 22 12 13 | P | Roger. |
| 22 12 16 | CC | MARK 12 minutes. |
| 22 12 18 | P | Roger. |
| 22 12 24 | P | . . . |
| 22 12 36 | CC | Faith Seven, you're cutting out, it's about LOS. See you next time around boy-san. |
| 22 12 41 | P | Roger. |

## CANARY ISLANDS (FIFTEENTH PASS)

| | | |
|---|---|---|
| 22 18 26 | CC | Faith Seven, this is Canary Cap Com. You need not acknowledge this transmission, requesting you turn on your TV and your S-band beacon if you have not already done so. |
| 22 18 40 | P | Roger. TV's on. |
| 22 18 49 | CC | This is Canary Cap Com. Did you put your—wait a minute, we're getting the body temperature now. |
| 22 19 17 | CC | This is Canary Cap Com. Surgeon requests that you hold your body temp probe in your mouth for about 1 more minute. |
| 22 20 01 | CC | This is Canary Cap Com. You may take the body temperature probe from your mouth now. Over. |
| 22 20 09 | P | Roger. Thank you. |
| 22 20 14 | CC | Your [contingency recovery area] 15-Bravo [retrosequence] time is nominal and request a partial $O_2$ readout, please. |
| 22 20 26 | P | Roger. My 15-Bravo is nominal. Cabin partial pressure $O_2$ is about 4.2 [psi]. |
| 22 20 34 | CC | Roger. Understand 4.2. I'd like to try to get a c.e.t. clock error here; so I'm going to give you a time hack. I'd like for you to give me the difference in the clocks. On my mark the time will be 22 20 40. MARK. (22 20 57)[T] |
| 22 20 58 | P | . . . |
| 22 21 01 | CC | Understand 15 seconds. |
| 22 21 05 | CC | Roger. . . . . |
| 22 21 07 | P | Roger. Understand. |
| 22 21 29 | CC | Astro confirms 15. Over. |
| 22 21 35 | ? | Roger. |
| 22 22 15 | CC | This is Canary Cap Com. Could you give me a cabin-pressure readout, please? |
| 22 22 20 | P | Roger. Cabin pressure 5.2 [psi]. |
| 22 22 23 | CC | Roger. |
| 22 23 37 | CC | We're getting pretty close to LOS here. Request you turn TV off and the S-band beacon to ground command. Over. |
| 22 23 44 | P | Roger. TV off and S-band beacon to ground command. |
| 22 23 47 | CC | Roger. |

## KANO (FIFTEENTH PASS)

| | | |
|---|---|---|
| 22 27 16 | CC | Faith Seven, this is Kano Cap Com. We have T/M solid. We would like a cabin (heat- |
| 22 27 24 | P | exchanger) dome temperature. That is the only high reading. Over. |
| | | . . . |
| 22 27 34 | CC | Say again. |
| Unreadable | P | . . . |
| 27 27 44 | CC | Roger. |
| ?2 27 49 | CC | Astro, have you eaten? Over. |
| 22 27 58 | CC | Astro, this is Kano Cap Com. Have you eaten? Over. |
| 22 28 03 | P | . . . Cabin dome is 72 degrees. |
| Unreadable | CC | Roger. Have you eaten? Over. |

## ZANZIBAR (FIFTEENTH PASS)

| | | |
|---|---|---|
| 22 36 27 | CC | Faith Seven, Zanzibar Cap Com. |
| 22 36 29 | P | Roger, Zanzibar, Faith Seven. |
| 22 36 32 | CC | T/M looks good on the ground here. We have no big problems. Like to have fuel and oxygen readings. |
| 22 36 39 | P | Roger. . . . fuel, auto . . ., manual 95 percent. Oxygen 150 percent primary, and 100 percent secondary. |
| 22 36 53 | CC | Please repeat primary oxygen. |
| 22 36 56 | P | 150 percent. |
| 22 36 58 | CC | Roger. Your [recovery area] 16–1 [retrosequence] time, 23 31 03. 23 31 03. |
| 22 37 12 | P | 23 31 03. |
| 22 37 16 | CC | That is affirmative. That is g.e.t. and does not include your clock error. |
| 22 37 20 | P | Roger. |
| 22 37 26 | CC | Faith Seven. Have you eaten this morning? |
| 22 37 30 | P | Negative. Not yet this morning. |
| 22 37 33 | CC | Roger. |

| | | |
|---|---|---|
| 22 37 53 | CC | Faith Seven, Zanzibar Cap Com. The surgeon would like to know what—how you feel this morning? |
| 22 37 58 | P | Fine. Excellent. |
| 22 38 04 | CC | Very good. |
| 22 49 25 | P | And here comes the short status report again: Nitrogen regulated low pressure: auto, 475 [psi]; manual 490 [psi]. B-nut temperature: pitch down, 50 [degrees] pitch up, 49 [degrees]. Yaw left, 55 [degrees]; yaw right, 51 [degrees]. Roll counterclockwise, 78 [degrees]; roll clockwise, 78 [degrees]. Auto peroxide tank, 80 [degrees]; manual tank, 72 [degrees]; reserve tank, 73 [degrees]. Isolated bus voltage, 28. |

MUCHEA (FIFTEENTH PASS)

| | | |
|---|---|---|
| 22 53 25 | CC | Faith Seven, Muchea Cap Com. |
| 22 53 27 | P | Roger, Muchea Cap Com. Faith Seven. |
| 22 53 30 | CC | Are you checking your high thrusters? |
| 22 53 40 | CC | Are you checking your high thrusters? |
| 22 53 54 | CC | Faith Seven, Muchea Cap Com. Do you copy? |
| 22 53 56 | P | Roger, Muchea Cap Com. I am not . . . my thrusters. Over. |
| 22 54 01 | CC | Say again last. |
| 22 54 02 | P | I am not checking my thrusters. Over. |
| 22 54 05 | CC | Roger. We had a partial T/M dropout. |
| 22 54 10 | P | Roger. |
| 22 54 16 | CC | Have you made any checks on thrusters? |
| 22 54 19 | P | Roger. I made a couple of them, three different ones of them. I'm going to bring up my rate indicators shortly and check the rest of them. |
| 22 54 29 | CC | Roger. |
| 22 55 03 | CC | Systems report T/M looks good and aeromeds report you look good. |
| 22 55 07 | P | Roger. |
| 22 55 33 | CC | Are you changing the control valve setting on your suit heat exchanger? |
| 22 55 38 | P | Roger. Suit dome is on its way down very slowly. |
| 22 55 45 | CC | Roger. We concur. |
| 22 55 52 | CC | Have you had your breakfast? |
| 22 55 54 | P | Negative. |
| 22 57 00 | CC | Faith Seven. Could you give me a report on that thruster check? Which thrusters are okay? |
| 22 57 06 | P | Roger. I've checked my yaw thrusters both auto and manual. I'm going to ASCS bus and then turn my rate gyros on, and in first-light then check the remainder of my thrusters. |
| 22 57 24 | CC | Roger. |
| 22 57 26 | P | While alining the spacecraft. |
| 22 57 28 | CC | Say again. |
| 22 57 30 | P | I will check thrusters while alining spacecraft, while uncaging gyros. |
| 22 57 34 | CC | Roger. |
| 22 59 38 | CC | We have approximately 1 minute to LOS. |
| 22 59 42 | P | Roger. |
| 23 06 51 | P | *Just brought the rate indicators to manual on position, and they're indicating about a half of a degree right roll rate, half a degree pitch up rate, and 1 degree left yaw rate. I have now checked my manual proportional thrusters, and they all function correctly and C-band beacon on continuous. |

GUAYMAS (FIFTEENTH PASS)

| | | |
|---|---|---|
| 23 31 02 | CC | Faith Seven, Guaymas Cap Com. |
| 23 31 07 | P | Go ahead, Guaymas Cap Com, Faith Seven. |
| 23 31 09 | CC | You sound good, Gordo. Are you going to have time for the ASCS? |
| 23 31 14 | P | Roger. The ASCS is powered up. I powered it up about 1 minute ago. Right now, my rate indicators are powered up. |
| 23 31 27 | CC | Roger. Tape recorder continuous. |
| 23 31 30 | P | Roger. Tape recorder continuous. |
| 23 31 32 | CC | How about the C-band? |
| 23 31 35 | P | Roger. . . . . |

| | | |
|---|---|---|
| 23 31 36 | CC | Roger. Are you going to check your thrusters over here? |
| 23 31 44 | P | Roger. I've already checked my manual thrusters, and I've checked about half of my fly-by-wires. I'm going to wait 'til daylight and I'll get the rest of my fly-by-wires while I aline the spacecraft. |
| 23 31 59 | CC | Roger. You say you're waiting for daylight. |
| 23 32 01 | P | Roger. I'm going to aline the spacecraft with the thrusters while getting a check on the rest of them. |
| 23 32 08 | CC | Roger. |
| 23 32 21 | P | I'll check my fly-by-wires now and aline my spacecraft manually on the manual proportional. |
| Unreadable | CC | Roger. |
| 23 32 29 | P | Checking fly-by-wires now. Man, do those ever throw out the fire at night. |
| 23 32 48 | CC | Say again, Gordo. I didn't read that. |
| 23 32 49 | P | You can really see the sparks from the thrusters at night. |
| 23 32 53 | CC | Ha, ha! Roger. |
| 23 33 13 | P | Roger. All fly-by-wire low thrusters work correctly. |
| 23 33 18 | CC | Roger. |
| 23 33 29 | CC | Could you give me your fuel readings, Gordo? |
| 23 33 33 | P | Roger. I have 65 percent auto and 95 percent manual. |
| 23 33 38 | CC | Roger. |

CAPE CANAVERAL (SIXTEENTH PASS)

| | | |
|---|---|---|
| 23 36 44 | CC | Faith Seven, Cape Cap Com. Do you read? Over. |
| 23 36 46 | P | Roger, Cape Cap Com, Faith Seven. |
| 23 36 49 | CC | Roger. Welcome back, Gordo. |
| 23 36 52 | P | Roger. Thank you. |
| 23 36 53 | CC | I have a roll angle for you for your dim light study. Over. |
| 23 36 59 | P | Roger. Go ahead. |
| 23 37 01 | CC | Your angle is 34 degrees at sunset. That is, roll right, 34 degrees. |
| 23 37 08 | P | 34 degrees. Understand. |
| 23 37 10 | CC | Could you give me a reading of your cabin air? |
| 23 37 13 | P | Roger. Cabin air temp's about 86 degrees. |
| 23 37 17 | CC | Roger, 86. Have you had a good meal today? |
| 23 37 22 | P | Fairly good. |
| 23 37 25 | CC | Roger. |
| 23 37 27 | P | I'm alining the spacecraft now. |
| 23 37 33 | CC | Roger. Your attitudes look like you're almost in. |
| 23 37 39 | P | It would because the gyros are still caged. |
| 23 37 42 | CC | That's interesting. |
| 23 37 44 | P | I say they would because the gyros are still caged. |
| 23 37 47 | CC | Good deal. You've got real good attitudes on the caged gyros. |
| 23 37 50 | P | Roger. |
| 23 37 52 | CC | Did you read that I said roll right 34 degrees? |
| 23 37 55 | P | Roll right 34 degrees. Roger. |
| 23 38 09 | CC | Would you give us some TV, Gordo? |
| 23 38 27 | CC | Hello dahr. |
| 23 38 28 | P | Hello dahr. |
| 23 39 32 | CC | Faith Seven, Cape Cap Com. Would you give us a yell if you get an auto fuel light? Over. |
| 23 39 37 | P | Roger. |
| 23 40 57 | P | *Caged gyros coming to slave. |
| 23 41 02 | CC | Roger. |
| 23 41 20 | CC | Our scanners are checking out quite closely, Gordo. |
| 23 41 24 | P | Roger. |
| 23 42 36 | P | Going to auto. |
| 23 42 46 | P | Foiled it again. |
| 23 43 10 | CC | Faith Seven, Cape Cap Com. |
| 23 43 12 | P | Go ahead, Cape Cap Com, Faith Seven. |
| 23 43 15 | CC | Roger. You can kill your TV. Your scanners and attitudes match perfectly at LOS. |
| 23 43 21 | P | Roger. Thank you. |

| | | |
|---|---|---|
| 23 43 26 | P | I'm on auto control. |
| 23 43 28 | CC | Roger. Understand on auto control. |
| 23 43 30 | P | Roger. |
| | | *[Unconfirmed transmissions omitted.] |

CANARY ISLANDS (SIXTEENTH PASS)

| | | |
|---|---|---|
| 23 51 41 | CC | Faith Seven, this is Canary Cap Com. We have T/M solid. All systems are green. Do you confirm TV on? Over. |
| 23 51 53 | P | Roger. TV is on. |
| 23 53 34 | CC | This is Canary Cap Com. Could you send us a blood pressure now, if you please? |
| 23 53 39 | P | Roger. |
| 23 53 46 | CC | We are receiving blood pressure now. |
| 23 56 22 | CC | Faith Seven, would you take a deep breath and hold it, please? |
| 23 56 26 | P | Roger. |
| 23 56 31 | CC | Okay, exhale, exhale. |
| 23 57 03 | CC | Faith Seven, inhale, please. |
| 23 57 50 | CC | This is Canary Cap Com, we are coming up on LOS. You may turn off your TV camera, please. |
| 23 57 54 | P | Roger. |

KANO (SIXTEENTH PASS)

| | | |
|---|---|---|
| 23 58 01 | CC | Faith Seven, Kano has T/M solid. |
| 23 58 04 | P | Roger, Kano. All systems green here. |
| 23 58 07 | CC | I'll give you a check in a minute. Thank you. |
| 23 58 10 | P | Roger. |
| 23 58 12 | CC | They are all green on the ground. |
| 23 58 14 | P | Roger. |
| 23 59 36 | CC | Faith Seven, this is Kano Cap Com. |
| 23 59 40 | P | Go ahead, Kano. |
| 23 59 41 | CC | I thought I'd tell you that [contingency recovery] Area 16–B [retrosequence time] is nominal. |
| 23 59 45 | P | 16–B is nominal. Roger. Thank you. |
| 24 05 20 | CC | Site of Kano will have LOS at 13 08 56. |

ZANZIBAR (SIXTEENTH PASS)

| | | |
|---|---|---|
| 24 06 39 | P | Hello, Zanzibar, Faith Seven here. |
| 24 06 42 | CC | Faith Seven, Zanzibar Cap Com. Go ahead. |
| 24 06 45 | P | Roger. First, I have a message for you. |
| 24 06 47 | CC | Roger. |
| 24 06 51 | P | Hello Africa. This is Astronaut Gordon Cooper, speaking from Faith Seven. I am right now over 100 miles above Africa, speaking to the Zanzibar station. Just a few minutes ago, I passed Addis Ababa. I want to wish success to your leaders there. Good luck to all of you in Africa. |
| 24 07 12 | P | Are you ready for a consumable readout now? |
| 24 07 14 | CC | Go ahead. |
| 24 07 16 | P | Roger. Auto fuel, 63 [percent]; manual, 93 [percent]. Oxygen primary, 145 [percent], secondary 100 [percent]. |
| 24 07 29 | CC | Confirmed. T/M looks good on the ground here. |
| 24 07 36 | P | Roger. |
| 24 07 45 | CC | How does it feel on the second day, Gordo? |
| 24 07 48 | P | Fine. I may get used to this thing, yet. |
| 24 07 52 | CC | Roger. |
| 24 09 17 | CC | Faith Seven. Zanzibar Cap Com. |
| 24 09 18 | P | Go ahead, Zanzibar. |
| 24 09 20 | CC | The surgeon would like to know how deep is your breathing at the present time. |
| 24 09 26 | P | Roger. Not very deep. |
| 24 09 28 | CC | Roger. Thank you. |
| 24 09 30 | P | Here is a full breath. |

| | | |
|---|---|---|
| 24 09 34 | CC | Please repeat. |
| 24 09 35 | P | All right. Now I have a full breath in. |
| 24 09 39 | CC | You are taking full breaths. Very good. That's what our recording on the ground shows. |
| 24 09 43 | P | Roger. |
| 24 10 18 | P | I am now in auto control. Set up for the dim-light experiment. As soon as the Sun approaches the horizon, I will aline with the Sun. Fly-by-wire. Cage and put gyros free. Roll 34 degrees right, cage, gyros free. Back on auto and start taking the pictures. |
| 24 11 03 | CC | Faith Seven. Zanzibar Cap Com. |
| 24 11 06 | P | Go ahead, Zanzibar. |
| 24 11 08 | CC | How much tape do you have remaining on your recorder? |
| 24 11 12 | P | About 70 percent. |
| 24 11 14 | CC | Roger. Cape advises that you can go onto continuous tape recording. |
| 24 11 20 | P | Roger. |
| 24 13 50 | CC | Faith Seven. Zanzibar Cap Com. |
| 24 13 52 | P | Go ahead, Zanzibar. |
| 24 13 54 | CC | Clock readout now shows a +16 seconds. I will give you a mark at 24 13 50. |
| 24 14 02 | P | Roger. |
| 24 14 06 | CC | 1. MARK. (24 14 07) T |
| 24 14 10 | P | Roger. I was reading 24 14 07 at the time. That's about right—16 seconds. |
| 24 14 22 | CC | Roger. |
| 24 14 23 | P | Yeah. I was reading just 6, going to 7. That would be right. |
| 24 17 54 | P | Okay. The Sun is almost to the horizon. I'm going to fly-by-wire low—yawing over to the left just a little to get to the Sun. |
| 24 19 04 | P | I'm perfectly alined. Caging the gyros. Bang, bang. Gyros to free. I'm going to have to get them again. Quite alined in yaw. |
| 24 19 50 | P | Boy! This is going to be a doozy, right into the Sun. |
| 24 20 55 | P | Okay, gyros caged, to free, 34 degrees right. |
| 24 21 52 | P | Gyros caged; gyros free; auto orbit mode; lights off; warning lights off. |
| 24 22 31 | P | Here comes 1. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. 1,001. Number 2 exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Third exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Fourth exposure. Trip. 1,001. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Trip. 1, 2, 3. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Trip. 2, 3. Release. 1,001. 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Number 3. 1, 2, 3. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Number 4. 1, 2, 3. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10,<br>Here comes 1. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. 1,001. Number 2 exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Third exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Fourth exposure. Trip. 1,001. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Trip. 1, 2, 3. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Trip. 2, 3. Release. 1,001. 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Number 3. 1, 2, 3. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Number 4. 1, 2, 3. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. 10-second series. Trip. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Trip. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. Release. 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Trip. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Trip. 2, 3, 4, 5, 6, 7, 8, 9, 10. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. 30-second exposures. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. Trip. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. Release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. 1, 2, 3. Go ahead, Muchea. 5, 6, 7, 8, 9, 10, 11, 12. |

MUCHEA (SIXTEENTH PASS)

| | | |
|---|---|---|
| 24 27 57 | P | Roger. Status is green. |
| 24 28 00 | CC | Roger. We have it. |
| 24 28 02 | P | Dad burn it 21, 22, 23, 24. Roger. Thank you. Roger, I'm busy taking all these picture sequences, counting 1, 2, buckle-my-shoe type thing. |
| 24 28 23 | CC | Roger. |

| | | |
|---|---|---|
| 24 28 26 | P | Ha, ha !, I'm up to 5,244 now. Ha, ha ! |
| 24 28 43 | P | 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, release. 1, 2, 3, 4, 5, 6, 7, 8, 9. |
| 24 29 10 | CC | . . . Minus . . . pitch attitude and about a —14 on your horizon scanner pitch output. Would you check this? |
| 24 29 19 | P | Roger. I am on gyros free ; auto control ; gyros free ; pitch plane torquing on. |
| 24 29 27 | CC | Roger. |
| 24 29 28 | P | I am pitching around the plane of the ecliptic to take these pictures. |
| 24 29 31 | CC | Understand. |
| 24 29 43 | P | 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, release. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. Identifier pictures, two of them. Oops, tripped two accidently. I'm on slave. |
| 24 30 46 | P | Faith Seven is now gone to slave and will let the scanners process the spacecraft back around slowly. |
| 24 30 51 | CC | Roger. We concur here. |
| 24 31 07 | P | 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78. |
| 24 31 59 | CC | Pitch attitude and horizon scanners. |
| 24 32 01 | P | 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, just a minute 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20. |
| 24 32 33 | P | Roger. My gyros—it looks like I'm fairly closely on. I can see the actual horizon, and of course, my gyros are being precessed by the scanners back slowly because they were off quite a bit being gyros free and pitch plane precession on. |
| 24 32 50 | CC | Roger. . . . You are coming in here now, too. |
| 24 32 54 | P | Roger. I wasn't sure the spacecraft would fly this way, but it seems to be doing all right. |
| 24 33 01 | CC | Roger. |
| 24 33 07 | P | Now for the 30-second exposures. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. Roger. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. [223-second break here] |
| 24 37 44 | P | 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20. 30-second one coming. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. 10-second exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, off. |
| 24 40 54 | P | Okay. Third series. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20. |
| 24 42 29 | P | 30-second exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. 10-second exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. 10-second exposure over. I don't believe the camera tripped right. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. |
| 24 44 56 | P | Okay, starting the next series. MARK [24 45 01]$^{T_1}$ 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74. Go ahead, Canton. |

## CANTON (SIXTEENTH PASS)

| | | |
|---|---|---|
| 24 45 59 | CC | Roger. Your [recovery] Area 17–1 [retrosequence] time is 25 04 12. Over. |
| 24 46 08 | P | 25 04 02? |
| 24 46 12 | CC | Negative. 25 04 12. |
| 24 46 16 | P | Roger. 25 04 12. |
| 24 46 20 | CC | Affirmative. |
| 24 46 28 | P | That just about gets it. 30-second one. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. 10-second exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. |
| 24 48 51 | P | Radiation experiment went on 1 minute ago. |

| | | |
|---|---|---|
| 24 49 38 | P | Okay, one more series here for you. Starting NOW. (24 49 45)[T] 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, exposure off. 30-second exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. 10-second exposure. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, off. |
| 24 56 06 | P | The last series. 1 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, . . . . 30, 31, (etc.) 40, (etc.) 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, . . . 2, 3, . . . 14, 15, 16, . . . 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60. There is the 2-minute one off. 30-second one started. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. 10-second one on. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and a big fat hen and that one's off. |
| 24 58 24 | P | And my fuel quantity light came on at 61 percent at 24 58 25. |
| 25 00 25 | P | Here comes the sunrise pictures. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30. The 1-second one taken and off. |
| 25 01 50 | P | The second set of 30 and 1. 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, the 1-second one, and off. And that winds up the zodiacal lights [photography]. May they rest in peace. |

*[Unconfirmed transmission omitted.]

## GUAYMAS (SIXTEENTH PASS)

| | | |
|---|---|---|
| 25 03 22 | CC | Faith Seven, Guaymas Cap Com. |
| 25 03 25 | P | Roger, Guaymas go ahead. |
| 25 03 26 | CC | Have you started your photos yet? |
| 25 03 29 | P | Man, that's all I have been doing all night long. |
| 25 03 32 | CC | Roger, Hasselblad? |
| 25 03 34 | P | Roger, I'm just getting them out right now. |
| 25 03 37 | CC | Okay, you going to power down first or after? |
| 25 03 40 | P | No, I'll power down after I take the first two shots on it. Actually, I'm not going to power down until I finish those shots. I'm going to leave the gyros up to do the shots with. |
| 25 03 49 | CC | Okay. Do you want to give me a mark when you take them so I can get your times? |
| 25 03 53 | P | Roger. |
| 25 04 18 | P | I'm having a little trouble getting things out of Pandora's locker here. |
| 25 04 22 | CC | Roger. |
| 25 04 38 | P | Oh yeah, you might pass on to the Cape too, my fuel quantity warning light came on at 24 58, 24 hours and 58 minutes. |
| 25 04 50 | CC | Roger. |
| 25 04 58 | P | At 61 percent. |
| 25 05 04 | CC | Roger, Gordo. |
| 25 05 49 | P | Okay. I'm getting the first two shots right now. |
| 25 05 53 | CC | Roger. |
| 25 06 31 | P | Okay, that's the first two shots. |
| 25 06 36 | CC | Okay, Gordo. |
| 25 06 52 | P | Now, I'm going to fly-by-wire. |
| 25 07 11 | P | Yawing around to the 90 degree point on the gyro. |
| 25 07 17 | CC | Roger, we read you. |
| 25 08 54 | P | Okay, snapping two more pics. |
| 25 09 20 | P | Caging the gyros. |
| 25 09 27 | P | Get down in proper attitude first here. |
| 25 09 31 | CC | Okay. |
| 25 10 19 | P | Now it's back to free. |
| 25 11 49 | P | Two more pics. |

## CAPE CANAVERAL (SEVENTEENTH PASS)

| | | |
|---|---|---|
| 25 12 15 | CC | Helloooo up there. |
| 25 12 18 | P | Hello down dere. |
| 25 12 22 | P | Man, all I do is take pictures, pictures, pictures. |
| 25 12 26 | CC | All I do is clean, clean, clean. |
| 25 12 30 | P | Ha, ha. Roger. |
| 25 12 38 | P | I got all the zodiacal light pics and now I am busily engaged yawing around on the MIT jobbies. |
| 25 12 46 | CC | Roger. You have my sympathy. |
| 25 12 51 | P | I'm not complaining, ha, ha. |
| 25 12 57 | P | I'm at the 270 point now getting the last two pictures in the 30 seconds. |
| 25 13 02 | CC | I have 17-Bravo [contingency recovery area retrosequence time] correction, if you can take it. |
| 25 13 07 | P | Roger, better hang on just a minute, I'm right—snapping pictures—right at the second. |
| 25 13 13 | CC | Okay, standing by. |
| 25 14 12 | P | Okay. I can take it now. |
| 25 14 16 | CC | Roger. 17-Bravo, 26 14 48. |
| 25 14 25 | P | 26 14 48. |
| 25 14 28 | CC | That is affirmative. We'd like a little Sun gun time if you want to flip it on. |
| 25 14 37 | P | Say again. |
| 25 14 39 | CC | TV on for a couple of minutes please? |
| 25 14 44 | P | Roger, TV coming on. |
| 25 14 56 | CC | Gordo, for information only, if you care to use the 6-inch outside, recommending a minimum f stop 16 or 22 with the filter. It's not necessary to do this if you do use it outside; we recommend going this way. |
| 25 15 15 | P | At 22 with the filter, is that affirm? |
| 25 15 18 | CC | Say again, please. |
| 25 15 21 | P | 22 with filter. |
| 25 15 24 | CC | 16, f/16 with filter. |
| 25 15 28 | P | Roger. |
| 25 16 05 | P | Okay, I'm caging my gyros. |
| 25 16 10 | CC | Roger. |
| 25 16 13 | P | And they caged correctly. |
| 25 16 17 | CC | Good show; it works. |
| 25 16 18 | P | Yeah, just like advertised. |
| 25 16 22 | CC | How about that. |
| 25 16 28 | P | Powering down my ASCS bus. |
| 25 16 37 | CC | Roger. Understand ASCS bus is off. Your sure are a miser on the control fuel. |
| 25 16 47 | P | You say I'm noisy on the controls. |
| 25 16 51 | CC | I say you're miser on the controls. |
| 25 16 57 | P | Roger. |
| 25 17 51 | CC | . . . 1, 2, 3, 4, 5, do you read? |
| 25 17 54 | P | Roger, you are coming in very broken. Over. |
| 25 17 56 | CC | . . . |

## CANARY ISLANDS (SEVENTEENTH PASS)

| | | |
|---|---|---|
| 25 26 01 | CC | Faith Seven, this is Canary Cap Com. All systems are green. Do you confirm TV is on? Over. |
| 25 26 11 | P | Negative. TV is not on, Canary. I'm busy snapping some pictures. |
| 25 26 24 | P | TV coming on now. |
| 25 26 26 | CC | Roger. |
| 25 28 46 | SY | Faith Seven, Canary systems. |
| 25 28 48 | P | Go ahead Canary, Faith Seven. |
| 25 28 51 | SY | You're looking real good here, systems-wise. This is our last pass at you. We'll see you back in—back in Houston. Keep up the good work. |
| 25 28 59 | P | Roger, will do. Thanks a lot. |
| 25 29 35 | CC | This is Canary Cap Com, could you give us a cabin $O_2$ partial pressure readout, please. |
| 25 29 42 | P | Roger. Cabin $O_2$ partial pressure is about 3.9 [psi]. |
| 25 29 47 | CC | Roger. |
| 25 29 58 | CC | Was that 3.9 or 3.5? Over. |
| 25 30 02 | P | About 3.9. |

CANARY ISLANDS (SEVENTEENTH PASS)—Continued

| | | |
|---|---|---|
| 25 30 05 | P | Just a tad under 4. I'm going back on my suit. I've had my visor open for a while here. |
| 25 30 11 | CC | Roger. |
| 25 30 21 | CC | We're having T/M LOS here. Suggest you turn off your TV camera. Over. |
| 25 30 26 | P | Roger. |

KANO (SEVENTEENTH PASS)

| | | |
|---|---|---|
| 25 32 00 | CC | Faith Seven, this is Kano Cap Com. We have T/M solid, and all systems are go. |
| 25 32 06 | P | Roger Kano. Thank you. |
| 25 35 28 | CC | Faith Seven, this is Kano Cap Com. Your systems are still all green. Goodbye and good luck. Out. |
| 25 35 34 | P | Roger. Thank you Kano. |

ZANZIBAR (SEVENTEENTH PASS)

| | | |
|---|---|---|
| 25 41 50 | CC | Faith Seven, Zanzibar Cap Com. |
| 25 41 56 | P | Go ahead, Zanzibar. Faith Seven. |
| 25 41 58 | CC | Faith Seven, Zanzibar Cap Com. Your systems look good on the ground. |
| 25 42 05 | P | Roger, Zanzibar. They look good up here, too. |
| 25 42 08 | CC | Okay. Could I have consumable readouts, please? |
| 25 42 12 | P | Roger. Auto. fuel, 60 percent; manual fuel, 91 percent. Oxygen primary, 145 percent; secondary, 100 percent. |
| 25 42 28 | CC | Faith Seven, I read you. You are fading. |
| 25 42 34 | P | Roger. |
| 25 42 56 | CC | Faith Seven, Zanzibar Cap Com. Good luck on your pass. |
| 25 43 01 | P | Roger. Thank you. |
| 25 49 33 | P | Okay. Short status report: Nitrogen low pressure: auto., 470 [psi]; manual, 490 [psi]. B-nut temperatures: Pitch down, 75 [degrees]; pitch up, 58 [degrees]; yaw left, 70 [degrees]; yaw right, 70 [degrees]; roll counterclockwise, 96 [degrees]; roll clockwise, 95 [degrees]. Peroxide auto tank: . . . 2 [degrees]; peroxide manual tank, 70 [degrees], peroxide reserve tank, 76 [degrees]. 250 inverter, 116 [degrees]; 150 inverter, 128 [degrees]; standby inverter, 108 [degrees]. |

*[Non-flight-related transmission omitted.]

MUCHEA (SEVENTEENTH PASS)

| | | |
|---|---|---|
| 26 00 54 | CC | Faith Seven, Muchea Cap Com. |
| 26 00 57 | P | Howdy, Muchea Cap Com. Faith Seven. |
| 26 01 00 | CC | We have a systems go and aeromed go. |
| 26 01 49 | P | Very good. |
| 26 01 09 | CC | Aeromeds are standing by for blood pressure. |
| 26 01 12 | P | Roger, coming now. Does he know how to read it? |
| 26 01 20 | CC | Roger. They got it now. |
| 26 01 33 | CC | I have [recovery] Area 18–1 retrosequence time. Prepared to copy? |
| 26 01 40 | P | Roger. Stand by just a second. |
| 26 01 41 | CC | Roger. |
| 26 01 47 | P | Roger. Go. |
| 26 01 48 | CC | Area 18–1 [retrosequence time], 26 34 48. |
| 26 01 56 | P | Roger. 26 34 48. |
| 26 01 59 | CC | That's affirmative; [contingency recovery area] 18–A [retrosequence time] is 26 58 50. |
| 26 02 10 | P | That was [contingency recovery area] 18–A. |
| 26 02 12 | CC | Affirmative. |
| 26 02 16 | P | *I didn't get the rest of that, 26 what? |
| 26 02 24 | CC | 26 58 50. |
| 26 02 28 | P | Roger. 26 58 50. Roger. |
| 26 02 31 | CC | And I have [recovery area] 18–2 [retrosequence time]. 27 43 48. |
| 26 02 38 | P | Roger. 27 43 48. |
| 26 02 42 | CC | Roger. And these times does—do not include the clock error. |
| 26 02 47 | P | Roger. Understand. |
| 26 02 49 | CC | That first blood pressure was no good. Would you send another one? It was cut off early. |
| 26 03 03 | CC | Roger. We are getting your second blood pressure. |
| 26 03 29 | CC | That was a good blood pressure. |
| 26 03 32 | P | Roger. |

| | | |
|---|---|---|
| 26 03 35 | CC | Systems report that your suit dome temp is decreasing slowly. |
| 26 03 41 | P | Roger. I'm running it down fairly low. I got it a little bit high. |
| 26 03 45 | CC | Roger. |
| 26 03 48 | P | It's been running consistently fairly low. |
| 26 03 51 | CC | Understand. |
| 26 04 57 | CC | Faith Seven. We have a message for you. |
| 26 04 59 | P | Roger. |
| 26 05 02 | CC | From the Australian Minister of Supply, the Honorable Alan Fairhall: "All Australia following your progress with lively interest. Muchea and Red Lake tracking station staffs and Department of Supply are proud to be associated with this great NASA effort. Happy landings." End message. |
| 26 05 20 | P | Roger. Thank you very much. |
| 26 06 55 | CC | We have approximately 1 minute to LOS. |
| 26 06 58 | P | Roger. |
| 26 07 21 | CC | Could you give me a read on your partial $O_2$? |
| 26 07 26 | P | Roger. Cabin partial $O_2$ is about 3.9 [psi]. |
| 26 07 30 | CC | 3.9 [psi]. |
| 26 07 32 | P | Roger. |

CANTON (SEVENTEENTH PASS)

| | | |
|---|---|---|
| 26 20 17 | CC | Faith Seven, this is Canton Cap Com. Standing by. |
| 26 20 22 | P | Roger, Canton. I'm all green here. |

HAWAII (SEVENTEENTH PASS)

| | | |
|---|---|---|
| 26 27 00 | CC | Faith Seven, Hawaii. Do you read? |
| 26 27 04 | P | Roger, Hawaii. Faith Seven. |
| 26 27 06 | CC | Faith Seven. All systems are green. We are standing by. |
| 26 27 11 | P | Roger. Thank you. |
| 26 31 35 | P | * And, we are approaching 26 31. We are between Hawaii and California. Very, very low rates. Turning on my manual proportional control. Low rates. |
| 26 32 33 | P | I believe it's better to leave it as it is. |
| 26 32 43 | P | Now to get the camera out. |
| 26 34 06 | P | * And I made the first picture just then between—just off the west coast of the United States. Almost on the west coast. |
| 26 34 49 | P | Second one is coming in on the coastline. There are quite a bit of clouds, all different types and patterns. I took one getting in part of the coastline in under the clouds. That's number 2. |
| 26 35 12 | P | Snapping all these pics at f/5.6 and 1/125th. |

CALIFORNIA (SEVENTEENTH PASS)

| | | |
|---|---|---|
| 26 36 29 | CC | Faith Seven, this is California Cap. |
| 26 36 32 | P | Roger, California. Faith Seven. |
| 26 36 45 | CC | Faith Seven, this is California. We have you all green here on the ground. |
| 26 36 51 | P | Roger. Thank you. I'm all green here. |
| 26 36 54 | CC | Roger. When you take your photographs, will you turn your tape recorder to continuous? |
| 26 37 00 | P | Roger. I have the tape recorder on continuous. |
| 26 37 48 | P | Both of those pictures were made looking to—slightly to the south. |
| 26 39 55 | P | Looking back to the due west, inland on the desert area. In fact, there's the Salton Sea. |
| 26 40 16 | P | *There's the Gulf and Baja California. Next one. There's El Centro area. I can make out individual fields. Smoke from the smokestack down there. There's some roads, houses, a little airstrip. There's a dry lake. |

CAPE CANAVERAL (EIGHTEENTH PASS)

| | | |
|---|---|---|
| 26 43 28 | P | Faith Seven passing over Dallas. |
| 26 45 56 | CC | Faith Seven, this is Cape. Everything is go here. We are standing by. |
| 26 46 01 | P | Roger, Cape. Everything go here. |
| 26 46 15 | CC | Faith Seven. Would you like a G.m.t. hack? Over. |
| 26 46 21 | P | Roger. I would. |

| | | |
|---|---|---|
| 26 46 23 | CC | All right. On my mark, G.m.t. will be 15 50 30. Stand by, MARK. 15 50 30. (26 46 35)[T] |
| 26 46 40 | P | Roger. My G.m.t. clock is 10 seconds fast. |
| 26 46 47 | CC | Understand the capsule clock. |
| 26 46 53 | P | That's the capsule clock. |
| 26 46 55 | CC | Roger. |
| 26 46 59 | CC | I have a correction to Diamond Head, retrosequence time. Delta T, 4 minutes 08 seconds for Diamond Head. Over. |
| 26 47 11 | P | 10 minutes 08 seconds. |
| 26 47 15 | CC | . . . 08. |
| 26 47 16 | P | 4 minutes 08 seconds. |
| 26 47 21 | CC | That is correct. |
| 26 47 23 | P | Roger. |
| 26 47 28 | CC | And if you should be inclined to, use the extra black and white 16-millimeter magazine outside for general photography. Recommending f/16.0 since you have no filter. |
| Unreadable | P | Roger. |
| 26 47 51 | CC | We have no specific requirements for it, however. |
| 26 47 56 | P | Roger. |
| 26 53 13 | P | Radiation experiment coming on, NOW. [26 53 17][T]. I'm at about, —10 degrees on pitch, roll right about 10 degrees, facing back to the west. Slowly oscillating in a left yaw rate. |
| 26 56 08 | P | I'm opening the KK clamp and we'll see what happens here now . |
| 26 57 51 | P | *And it appears to be flowing—water out of the tin can. |
| 26 59 00 | P | Radiation experiment off. |
| 27 02 26 | P | The heat exchange dome temp immediately went down to the freezing point. Closing off KK clamp. I'll have to continue on the original suit circuit. |
| 27 09 15 | P | Starting on the second series of the MIT film, just short of Africa. Coastline should be coming in momentarily. Took a shot out over the water of unusual—of good sized cloud buildups. |
| 27 11 25 | P | *Now the suit heat exchanger dome temp's starting back up. About thawed out. |
| 27 16 38 | P | Okay, short status: Roll clockwise, 85 (degrees), roll counterclockwise, 90 (degrees); Yaw right, 68 (degrees); yaw left, 75 (degrees); Pitch up, 62 (degrees); pitch down, 74 (degrees). Retro temp., 75 (degrees). 250 inverter 108 (degrees); 150 inverter 124 (degrees); standby inverter 108 (degrees). Cabin outlet, 72 (degrees). Auto peroxide tank, 72 (degrees); manual peroxide tank, 72 (degrees); reserve peroxide tank, 75 (degrees). Correction on that—that auto peroxide tank is 82 (degrees). Isolated bus voltage, 28 volts. Camera going up in the glove box. |
| 27 26 08 | P | [Yawn] Man, I dropped off to sleep again for a few minutes there. |
| 27 29 50 | P | Now, looks like the 1.5 [comfort-control-valve] setting is holding the suit heat exchange dome temp for the moment. Almost down to the bottom, about 42 degrees. |
| 27 30 47 | P | Yo ho ho ho ho ho. [He is singing.] |
| 27 31 51 | P | Boy, what a beautiful view from up here. Surprises you every orbit. |

MUCHEA (EIGHTEENTH PASS)

| | | |
|---|---|---|
| 27 33 39 | CC | Faith Seven, Muchea Cap Com. Over. |
| 27 33 42 | P | Roger, Muchea. Faith Seven reading you loud and clear. |
| 27 33 46 | CC | Roger. Same. Would you place your telemetry switch in the continuous position please? |
| 27 33 50 | P | Roger. Coming continuous NOW. |
| 27 34 15 | CC | Roger. We have T/M. |
| 27 34 19 | P | Roger. |
| 27 35 11 | CC | I have some retrosequence times when you're ready to copy. |
| 27 35 18 | P | Roger. Go. |
| 27 35 21 | CC | Area 19–A [contingency recovery area] nominal. |
| 27 35 28 | P | Roger. |
| 27 35 29 | CC | 19–B, 28 31 24. Area 19–C, nominal. |
| 27 35 45 | P | Roger. |
| 27 35 51 | CC | Would you read back area 19–B time? |
| 27 35 53 | P | Roger. 28 31 24. |
| 27 35 57 | CC | Roger. |
| 27 36 34 | CC | Systems here are go and aeromed is go. |
| 27 36 40 | P | Roger. Thank you, I'm go from here. |

| | | |
|---|---|---|
| 27 37 03 | P | Tell Warren to be careful and not get stuck. |
| 27 37 06 | CC | Ha, ha. He knows about that. |
| 27 37 12 | P | Roger. |
| 27 37 23 | CC | Stuck on what? |
| 27 37 26 | P | On the outback. |
| 27 37 28 | CC | Roger. Acknowledge. |
| 27 37 31 | P | Roger. |
| 27 37 57 | CC | By the way, we have all joined tennis clubs. |
| 27 38 02 | P | Excellent. That's the best thing to do. |
| 27 38 05 | CC | Roger. |
| 27 39 57 | CC | Faith Seven, Muchea Cap Com. We read a very low suit dome temp. |
| 27 40 02 | P | Roger. I'm running it very low. I'm working it back up now. |
| 27 40 17 | CC | Say again, Faith Seven. |
| 27 40 19 | P | *Roger. I've already made a decrease in setting. It should be coming back up shortly. |
| 27 41 51 | P | *The suit dome temp is still acting up. Suit inlet temp is back up to about 68 degrees. The suit dome temp has gone down to about 38 degrees. Have suit coolant almost off now. |
| 27 43 52 | P | All right, suit coolant is shut completely off. Now it should come up. |
| 27 50 10 | ? | . . . read you loud and clear. |
| 27 50 45 | P | Some of this fine plumbing they put in this thing. This sad thing on the needle—on the diaphragm fitting has come out so I can't change the needle to any other fitting. I'll have to leave the Kenny Kleinknecht clamp closed. Meantime, I can't pump any more. That container is full and so is the other one. |
| 27 52 24 | P | I wish some of you guys who tried to stick in some of this plumbing and—connected here and there, and use it here and there would sit in here awhile and try and use the stuff. |
| 27 55 33 | P | Wow! Look at that bright sunshine. Oooo, weee! |

HAWAII (EIGHTEENTH PASS)

| | | |
|---|---|---|
| 28 00 28 | CC | Faith Seven, Hawaii. Do you read? Over. |
| 28 00 32 | P | Roger, Hawaii. Faith Seven reading you aloud and clear. |
| 28 00 35 | CC | Read you loud and clear. All systems are green. Standing by for fuel and $O_2$ readout. |
| 28 00 40 | P | Roger. Fuel, 60/90 [percent]. Oxygen, 140/100 [percent]. |
| 28 00 55 | CC | Say again, $O_2$ primary, please. |
| 28 00 57 | P | 140 [percent], one four zero. |
| 28 01 01 | CC | Roger. Understand everything is green. |
| 28 01 04 | P | Roger. Thank you. |
| 28 01 56 | CC | Faith Seven, Hawaii. |
| 28 02 00 | P | Go ahead, Hawaii. Faith Seven. |
| 28 02 02 | CC | C-band in the continuous position? |
| 28 02 05 | P | Roger. It is. |
| 28 02 06 | CC | All right. |

CALIFORNIA (EIGHTEENTH PASS)

| | | |
|---|---|---|
| 28 08 07 | CC | Faith Seven, this is California Cap Com. |
| 28 08 11 | P | Roger, California. Faith Seven. |
| 28 08 13 | CC | Roger. We have you green clear across the board here. |
| 28 08 18 | P | Roger. Good. |
| 28 08 19 | CC | California standing by. |
| 28 08 23 | P | Roger. |
| 28 13 10 | P | Faith Seven passing over Baja California now. See entire Baja California. |
| 28 13 25 | CC | Faith Seven. Were you calling California? |
| 28 13 27 | P | Negative. I was just commenting that I could see all of Baja California. It's all clear, all up and down. |
| 28 13 38 | P | Disregard. |
| 28 13 40 | CC | Roger, Faith Seven. |
| 28 16 39 | P | Faith Seven passing over Houston, Texas. Have it in sight loud and clear. |

## CAPE CANAVERAL (NINETEENTH PASS)

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|---|---|---|
| 28 16 46 | CC | Roger, Seven. We read that at the Cape. |
| 28 16 50 | P | Roger. |
| 28 17 07 | CC | Faith Seven, this is Cape. We would like to see your TV returns, over. |
| 28 17 12 | P | Roger. I've got her on. |
| 28 17 40 | CC | Faith Seven, this is Cape. |
| 28 17 43 | P | Go ahead, Cape. |
| 28 17 45 | CC | I have you ATC [Air Traffic Control] clearance. Are you ready to copy? |
| 28 17 49 | P | Roger. |
| 28 17 51 | CC | "Please pass to Major Cooper, in flight, from Air Force Secretary Zuckert and Chief of Staff General LeMay: 'It is with great pride and enthusiasm that the entire United States Air Force is following the progress of your historic flight—a dramatic contribution to aerospace exploration. God luck, and God speed.'" Over. |
| 28 18 21 | P | Roger. Thank you. |
| 28 18 24 | CC | That's all right, Colonel. |
| 28 18 37 | CC | Faith Seven from Cape. Could you give me a comment on your general comfort, please? |
| 28 18 44 | P | * Roger. My general comfort is good, now. I've had a continuing battle with the plumbing in here. I was not able to open the KK clamp due to the fact that—that system is full of water. One of the needles broke off—or the little insert into it broke—and I am unable to transfer any more water out of the condensate tank. |
| 28 19 09 | CC | Roger. I gather you are not bothered by it. |
| 28 19 13 | P | Negative. I am plenty comfortable. I've had trouble with the suit heat exchanger; keep having to run it up and down and chase it, but it's doing fine. |
| 28 19 23 | CC | Looks like you are doing a real good job on that. Apparently you are keeping yourself very comfortable. |
| 28 19 28 | P | Roger. |
| 28 19 30 | CC | I assume since you've had trouble with this clamp, that it is now in the—rather, since you've had trouble with the condensate transfer, that the clamp is now in the closed position. |
| 28 19 41 | P | That's affirmative. |
| 28 19 44 | CC | Roger. Good show. |
| 28 19 53 | P | Are you getting any TV yet? |
| 28 19 57 | CC | I think the light is low inside there, Gordo. |
| 28 20 01 | P | I'm outside. |
| 28 20 09 | CC | Are you in the Sun? |
| 28 20 10 | P | Negative. |
| 28 20 12 | CC | I recommend you turn it off. |
| 28 20 14 | P | Roger. |
| 28 20 18 | CC | Also, how about the little squeezers, have they been beating their hearts out every 10 minutes? |
| 28 20 24 | P | Roger. Faithfully, every 10 minutes throughout the whole day and night, every time. |
| 28 20 31 | CC | A couple of beady yellow eyes, huh? |
| 28 20 42 | P | Ha, ha, Roger. I'm directly over Miami. I'm looking right down on Miami Beach. |
| 28 20 48 | CC | . . . |
| 28 21 39 | CC | Faith Seven, this is Cape. Would you give us a blood pressure now, please? |
| 28 21 43 | P | Roger. |
| 28 31 44 | P | Okay, you guys will have had it now . . . another measure . . . . |
| 28 41 31 | P | Drink some water. |
| 28 55 34 | P | Okay. Radiation experiment coming on now. |
| 28 55 48 | P | I'm in full drifting flight, so I'll have random attitudes for it. |
| 28 59 51 | P | At 28 59, my 0.05g telelight came on after I turned my warning lights off and back on to dim. Have turned my 0.05g and emergency 0.05g switch fuse off. |
| 29 02 38 | P | Radiation measurement is off. |
| 29 24 19 | P | For my short status report: Peroxide regulated pressure: auto, 470 [psi]; manual, 490 [psi]. 75 [degrees] pitch down; 60 [degrees] pitch up. Yaw left is 80 [degrees]; yaw right is 65 [degrees]. Roll counterclockwise is 78 [degrees]; roll clockwise is 75 [degrees]. Auto peroxide outlet, 72 [degrees]; manual is 72 [degrees]; reserve, 75 [degrees]. |

## HAWAII (NINETEENTH PASS)

| | | |
|---|---|---|
| 29 28 15 | CC | Faith Seven, Hawaii on air-to-ground relay, do you read? Over. |
| 29 28 19 | P | Roger, Hawaii. Faith Seven reading you loud and clear. |
| 29 28 29 | P | Roger. Faith—Faith Seven is reading you loud and clear, Hawaii. |

| | | |
|---|---|---|
| 29 34 07 | P | Hawaii Cap Com, Faith Seven. |
| 29 34 09 | CC | Go ahead, Seven, this is Hawaii. Read you loud and clear. |
| 29 34 13 | P | Roger. Wonder if you would relay to the Cape a little situation I had happen and see what they think on it. While turning my warning lights off and back on to dim, my 0.05g telelight came on in my telelight panel. Now the action that I have taken is, to turn off my 0.05g switch fuse and my emergency 0.05g switch fuse. Would you relay to them, and get their idea on it? Over. |
| 29 34 44 | CC | Understand your 0.05g light came on and your turned your 0.05g fuse switch and emergency 0.05g fuse switch off. |
| 29 34 56 | P | That's affirmative. |
| 29 34 59 | CC | Is that affirmative? |
| 29 35 01 | P | Affirmative. |
| 29 35 02 | CC | Can we have T/M on? |
| 29 35 06 | P | Roger. T/M is on now, have it on ground command. |
| 29 35 10 | CC | I have retrosequence time for [contingency recovery] area 20–Alpha, is nominal. |
| 29 35 18 | P | Roger. 20–Alpha is nominal. Thank you. |
| 29 35 22 | CC | We also pass on to you—turn C-band beacon on, a g.e.t. of 30 58 00. |
| 29 35 33 | P | 30 58 00. |
| 29 35 37 | CC | Roger. Turn off at 31 08 00. |
| 29 35 56 | CC | Did you copy, Seven? |
| 29 35 57 | P | Negative. I got 30 58 00 on. |
| 29 36 02 | CC | Roger. Turn it off 10 minutes later. |
| 29 36 05 | P | Roger. Will do. |
| 29 36 19 | CC | Seven, this is Hawaii. Was that a red or a green telelight? |
| 29 36 38 | CC | Faith Seven, Hawaii. Do you read? Over. |
| 29 36 40 | P | Roger. Go ahead, Hawaii. Faith Seven. |
| 29 36 42 | CC | Roger. Was your 0.05g light red or green? |
| 29 36 46 | P | It was green. Over. |
| 29 36 50 | CC | Consumable readout please. |
| 29 36 52 | P | Roger. Fuel: 58 [percent] auto.; 90 [percent] manual. Oxygen: 140 [percent] primary; 100 [percent] secondary. |
| 29 37 02 | CC | Roger. Understand. |
| 29 37 28 | CC | Seven, this is Hawaii Cap Com. |
| 29 37 31 | P | Go ahead, Hawaii. Seven. |
| 29 37 37 | CC | Faith Seven, Hawaii. Over. |
| 29 37 39 | P | Go ahead, Hawaii. Faith Seven. |

CALIFORNIA (NINETEENTH PASS)

| | | |
|---|---|---|
| 29 41 32 | CC | Faith Seven, Faith Seven. This is California Cap Com. |
| 29 41 35 | P | Roger, California Cap Com. Faith Seven here. |
| 29 41 39 | CC | Roger, Faith Seven. Our panel looks good. Telemetry does not indicate 0.05g. |
| 29 41 52 | P | Roger. It must be a . . . . I just threw a glitch into the light when I was turning my warning lights off and on, then, probably. |
| 29 42 02 | CC | There is a little diode in your light test, that failed could cause that light to come on. |
| 29 42 08 | P | Roger. Does MCC recommend that I go ahead and put my 0.05 and emergency 0.05g switch fuses back on? |
| 29 42 21 | CC | Faith Seven. Leave them off. |
| 29 42 25 | P | Roger. |

GUAYMAS (NINETEENTH PASS)

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|---|---|---|
| 29 44 07 | P | Go ahead, Guaymas. Faith Seven. |
| 29 44 09 | CC | I have some retrosequence times for you, for [recovery area] area 20–1. |
| 29 44 16 | P | Roger. |
| 29 44 17 | CC | 30 53 01. |
| 29 44 22 | P | Well, just a minute. Which one is that? |
| 29 44 25 | CC | Area 20–1. |
| 29 44 28 | P | Roger. 30. |
| 29 44 30 | CC | 53 01. |
| 29 44 33 | P | 53 01. Roger. |
| 29 44 34 | CC | Roger. And [contingency recovery] areas 20–B, C, and D are nominal. |

| | | |
|---|---|---|
| 29 44 42 | P | Roger. Understand. Thank you. |
| 29 44 45 | CC | Roger. And 20–1 doesn't take in your clock error. |
| 29 44 49 | P | Roger. Understand. |
| 29 48 38 | CC | Faith Seven. Guaymas Cap Com. |
| 29 48 40 | P | Go ahead, Guaymas. Faith Seven. |
| 29 48 42 | CC | *Would you go ahead and power up your ASCS bus? We would like to know if you have your amp cal programer. |
| 29 48 50 | CC | . . . gyros caged now? |
| 29 48 51 | P | Gyros are caged. Fly-by-wire; ASCS coming on normal now. |
| 29 49 25 | P | Guaymas, are you still reading me? |
| 29 49 29 | CC | Go ahead, Faith Seven. |
| 29 49 32 | P | Roger. You still have me on telemetry? |
| 29 49 35 | CC | Roger. You look good. |
| 29 49 37 | P | Roger. I am supposed to do this HF antenna test, now. |
| 29 49 43 | CC | Roger. |
| 29 49 49 | P | I will be on HF for a couple of minutes and then back on UHF. |
| 29 50 13 | P | This is Faith Seven on high frequency. Capsule elapsed time, 29 50 20. Now for HF antenna test. My attitudes are zero [degrees] in roll; am rolling 90 degrees and repeating. |
| 29 51 37 | P | This is Faith Seven on the second portion of the HF antenna test. C.e.t. 29 51 45. Now I am rolled 90 degrees. HF out. |
| Unreadable | P | Faith Seven is back on UHF. |

CAPE CANAVERAL (TWENTIETH PASS)

| | | |
|---|---|---|
| 29 52 26 | CC | Faith Seven. This is Cape. How do you read? Over. |
| 29 52 29 | P | Roger, Cape. Faith Seven reading you loud and clear. |
| 29 52 32 | CC | Roger, Gordo. On this 0.05g business, we are interested in whether or not the amp cal has switched to 0.05g logic. Do you follow? |
| 29 52 43 | P | Roger. |
| 29 52 44 | CC | * We figured the best way to do it—after gyros have warmed up—is to uncage, initiate a slow rate in any axis, and see if you have attitudes. If you do have attitudes, we feel that the amp cal has not latched at 0.05g. Over. |
| 29 53 01 | P | Roger. Assume a slow rate in any axis and see if the attitudes follow. Right? |
| 29 53 09 | CC | Right. When you uncage the gyros, you'll have to set up a very slow rate and see if you have attitude indications. |
| 29 53 16 | P | Roger. |
| 29 54 04 | CC | Seven, from Cape. We may have LOS before you are able to do this. Once you have done it, report to us through some other station, and then power down the ASCS after your test is complete. |
| 29 54 18 | P | Roger. |
| 29 55 07 | CC | Seven from Cape. Have you uncaged gyros yet? |
| 29 55 10 | P | Negative. Not yet. |
| 29 55 14 | CC | All right. We may lose you. Advise the next station. |
| 29 55 19 | P | Roger. |
| 29 55 21 | CC | Try to advise us even if we've had LOS. |
| 29 55 29 | P | Roger. |
| 29 57 41 | P | Cape. Faith Seven here. |
| 29 58 13 | P | Cape Cap Com. This is Faith Seven on high frequency. How do you read on this? Over. |
| Unreadable | CC | . . . |
| 29 58 28 | P | Cape Cap Com. Faith Seven, on high frequency. |
| Unreadable | CC | . . . |
| 29 59 09 | P | Hello, Cape. Faith Seven on high frequency. Over. |
| Unreadable | CC | . . . |

COASTAL SENTRY QUEBEC (TWENTIETH PASS)

| | | |
|---|---|---|
| 30 48 03 | CC | Hello, Faith Seven . . . |
| 30 48 13 | P | Roger, Faith Seven here. Go ahead. |
| 30 48 16 | CC | . . . |
| 30 48 48 | P | Faith Seven, here. Go ahead, John, just barely read you. |
| 30 49 02 | ? | . . . |

| | | |
|---|---|---|
| 30 50 36 | CC | Hello, Faith Seven. Hello, Faith Seven, this is CSQ Cap Com calling early. If you read me, Gordo, answer on HF. Over. |
| 30 50 58 | P | Roger, John. This is Faith Seven. Reading you about 4 by 4. How me? |
| 30 51 05 | CC | Hello, Faith Seven. CSQ Cap Com reads you very weak and unreadable. If you can read, give me status of your ASCS check, please. Over. |
| 30 51 17 | P | Roger. My amp cal is latched up 0.05g. I do not have ASCS. Over. |
| 30 51 25 | CC | Understand you do not have ASCS. Is that affirmed? |
| 30 51 29 | P | That is affirm. |
| 30 51 37 | CC | Faith Seven, this is CSQ. Can you say again, trouble with your amp cal? I did not receive that part of your transmission. Over. |
| 30 51 45 | P | Roger. My 0.05g portion of the logic is latched in on the amp cal, so I do not have attitude indications through the auto pilot any more. |
| 30 52 01 | CC | Roger . . . amp cal . . . Gordo, understand the amp cal is not working and the ASCS is inoperative. Was your gyro in the slaved position when you overturned? Over. |
| 30 52 11 | P | Say again. |
| 30 52 58 | P | This is Faith Seven on UHF. How do you read, CSQ? |
| 30 53 33 | CC | Faith Seven, CSQ Cap Com. Do you still receive me? Over. |
| 30 53 37 | P | Roger, CSQ. Faith Seven on UHF. How do you read? Over. |
| 30 53 41 | CC | Roger. Still reading you, Gordo. Did you have any of your gyros switched to slave during the ASCS check? Over. |
| 30 53 47 | P | *Roger. I had them caged, and then I went to slave; and in moving my rates, I did not get any attitudes. Over. |
| 30 53 59 | CC | Roger. Understand. No attitudes. Did you go into roll at all? Over. |
| 30 54 03 | P | Roger. I tried roll, pitch, and yaw. Over. |
| 30 54 07 | CC | Roger. You did not go into automatic roll. Is that affirmative? |
| 30 54 11 | P | *I did not power up the ASCS. All I did was turn my ASCS on, powered up my ASCS a-c bus. And when it was warmed up, then uncaged my gyros to the slave position, which should give me attitude. |
| 30 54 30 | P | And if . . . . |
| 30 54 32 | CC | Repeat that please. We don't have much time. Over. |
| 30 54 34 | P | Roger. I do not have attitudes when I go to slave on my gyros. When I uncage my gyros, I do not have attitude indications with the ASCS a-c powered up. |
| 30 54 48 | CC | Understand you did not go into actual ASCS. Is that affirmative? |
| 30 54 51 | P | Negative. I did not. |
| 30 55 39 | CC | Faith Seven, . . . . |
| 30 55 41 | P | Roger. Reading you loud and clear. |
| 30 55 44 | CC | Roger. I am reading you rather weak. You did not go on ASCS. You powered up, and went to the slave position; got no gyro indication. Is that affirmative? |
| 30 55 58 | P | That is affirm, affirm. |
| 30 56 05 | CC | Hello, Faith Seven. Be sure your T/M transmitter is on, and C-band beacon is on, for Range Tracker pass. I repeat, make sure C-band beacon is on the T/M is on for the Range Tracker pass. |
| 30 56 21 | P | Roger. It's on. |
| 30 56 32 | CC | Hello, Faith Seven. This is CSQ Cap Com. . . . on. Acknowledge please. Over. |
| 30 56 44 | P | Roger. They are on. Affirm, John. |

HAWAII (TWENTIETH PASS)

| | | |
|---|---|---|
| 31 00 30 | CC (CNV) | Faith Seven, this is Cape Cap Com. Over. [Loud squeal.] |
| 31 00 33 | P | Roger. Go ahead, Cape Cap Com. Faith Seven. |
| 31 00 49 | CC (CNV) | Faith Seven. this is Cape Cap Com. Over. [Loud squeal.] |
| 31 00 53 | P | Roger. Cape Cap Com, Faith Seven here. Go ahead. |
| 31 00 57 | CC (CNV) | Roger Gordo. . . . your amp cal is probably locked up on 0.05g. We are interested in just how much of your amp cal is working. |
| 31 01 08 | P | You're not coming through at all, Al. |
| 31 01 11 | CC (CNV) | . . . |
| 31 01 14 | P | Negative, I'm not reading you. |
| 31 01 17 | CC (CNV) | . . . |

| | | |
|---|---|---|
| 31 01 23 | P | Al, I can't read you. My amp cal is locked up on 0.05g. I do not have attitude indicators. Over. |
| 31 01 33 | CC (CNV) | Roger. Roger. Can you read me now? |
| 31 01 37 | P | Just barely. |
| 31 01 39 | CC (CNV) | Roger. Stand by a few minutes. |
| 31 02 00 | CC (CNV) | Hello, Faith Seven. How do you read me now? |
| 31 02 06 | P | A little bit better. |
| 31 02 09 | CC (CNV) | Faith Seven, I do understand that you do not have attitude indications? . . . do you read? |
| 31 02 20 | P | Negative. I'm not able to understand you yet. Over. |
| 31 02 29 | CC (CNV) | Okay. Stand by. |
| 31 02 50 | CC (CNV) | Seven, from Cape. How do you read? |
| 31 02 51 | P | Roger. Reading you better now. |
| 31 03 14 | CC (CNV) | Seven, from Cape. How do you read now? |
| 31 03 17 | P | Roger. Reading you loud and clear now. |
| 31 03 25 | P | Roger, Cape. Reading you loud and clear now. |
| 31 03 28 | CC (CNV) | Roger. We're interesting in how much of your amp cal is still available to you. |
| 31 03 42 | CC (CNV) | Seven, we would like you to do a how-de-doody test over Hawaii, to find out how much of your amp cal is still available. |
| 31 03 52 | P | Roger. Do you say you want me to power up my ASCS? |
| 31 04 12 | P | Cape Cap Com, say again. You were cut out on that. Over. |
| 31 04 30 | CC | Faith Seven, Hawaii Cap Com. Do you read? |
| 31 04 33 | P | A little bit, Scott. |
| 31 05 01 | CC | Seven, Faith Seven, Hawaii Cap Com. |
| 31 05 04 | P | Roger, Hawaii. Faith Seven. |
| Unreadable | CC | Go ahead Cape. |
| 31 05 06 | F | *We want to use the transfer to your circuit and let Cape Cap Com talk with him this pass. |
| 31 05 14 | CC | Roger. You are relaying at this time. |
| 31 05 17 | F | Roger. Would you also make sure that your people are prepared to watch for the T/M signal also. After this pass, we would appreciate if you'd play your last pass over again to make sure that you understand what we want in regards to what happened to the 0.05 g light between the time you got acquisition of the . . . |
| 31 05 47 | CC | Roger, I copied. |
| Unreadable | SY | Hawaii command carrier on. |
| 31 07 01 | P | Hello, Hawaii. Are you reading Faith Seven now? Over. |
| 31 07 24 | CC (CNV) | Faith Seven, this is Cape. Over. |
| 31 07 27 | P | Roger, Cape. Faith Seven here. |
| 31 07 37 | P | Roger, Cape. Faith Seven here. |
| 31 07 40 | P | Roger, Cape. Faith Seven here. Go ahead. |
| 31 07 43 | CC (CNV) | . . . |
| 31 07 53 | P | You're cutting in and out, I understand you want to find out how much of my amp cal is gone. |
| 31 08 00 | CC (CNV) | Affirmative. We would like to have you first switch your ASCS 0.05g fuse switch on and check the 0.05g light. |
| 31 08 11 | P | Roger. I'll do that now. |
| 31 08 20 | P | Roger. When I have put my ASCS 0.05g switch fuse on, my light comes green. Over. |
| 31 08 28 | CC (CNV) | Roger. Turn that fuse switch off and put your emergency 0.05g fuse switch on and check the light, please. |
| 31 08 35 | P | Roger. |
| 31 08 40 | P | With the ASCS 0.05g switch fuse off and emergency 0.05g switch fuse on, the light is not green. Over. |

| | | |
|---|---|---|
| 31 08 50 | CC (CNV) | Roger. In the meantime, Hawaii will check T/M. Do not forget that we would like . . . fly-by-wire. . . . |
| 31 09 27 | P | You were cutting in and out. I didn't get any of that, over. |
| 31 09 31 | CC (CNV) | Okay. We will try it one more time. . . . Over. |
| 31 09 57 | P | Roger. To go into auto and check for what? |
| 31 10 00 | CC (CNV) | . . . 0.05g. |
| 31 10 08 | P | You were cut out. |
| 31 10 11 | CC (CNV) | Roger. We would like to have you check for the roll rate which occurs after 0.05g. |
| 31 10 18 | P | Roger. Understand. |
| 31 10 21 | CC (CNV) | If you get this rate . . . . |
| 31 15 22 | P | Retro temp is 80 [degrees]. Pitch down is 70 [degrees]; pitch up is 65 [degrees]. Yaw left, 80 [degrees]; yaw right, 62 [degrees]. Roll counterclockwise, 72 [degrees]; roll clockwise, 68 [degrees]. Auto peroxide tank, 80 [degrees]; manual, 70 [degrees]; reserve, 72 [degrees]. 250 inverter, 101 [degrees]; 150 inverter, 121 [degrees]; standby inverter, 98 [degrees]. |

CALIFORNIA (TWENTIETH PASS)

| | | |
|---|---|---|
| 31 16 44 | CC | Faith Seven, Faith Seven, California Cap Com. |
| 31 16 47 | P | Roger, California, Faith Seven. Loud and clear. |
| 31 16 51 | CC | Be sure when you check for roll rate that the ASCS 0.05g fuse switch is in the on position. |
| 31 16 59 | P | Roger. |
| 31 17 03 | CC | . . . |
| 31 17 08 | P | *I have both fuse switches in the on position. My ASCS a-c bus is powered. I'm going to gyros slave. Now I understand I'm to go on to auto. Is that affirm? |
| 31 17 26 | CC | Say again, Faith Seven. |
| 31 17 28 | P | Roger. I have ASCS bus powered. Gyros are slaved, and now I understand that they want me to go into auto and see if I get the roll rate. Over. |
| 31 17 39 | CC | This is affirmative, Faith Seven. |
| 31 17 42 | P | Roger. Then do I come right back off with it if I get the roll rate? Over. |
| 31 17 46 | CC | *This is true. You can stop the capsule with the fly-by-wire. |
| 31 17 50 | P | Roger. Going into auto, NOW. [31 17 52] T |
| 31 17 58 | P | Roger. I do have the roll rate. |

GUAYMAS (TWENTIETH PASS)

| | | |
|---|---|---|
| 31 18 25 | CC | Guaymas, Cap Com. |
| 31 18 26 | P | Go ahead, Guaymas. Faith Seven. |
| 31 18 29 | CC (CAL) | You can turn off the ASCS now. |
| Unreadable | CC | And turn the 0.05g ASCS fuse switch off and the . . . . |
| 31 18 39 | P | Roger. I have my ASCS 0.05g switch fuse off, and I'm powering down the ASCS. Is that affirmative? |
| 31 18 49 | CC | Power down your ASCS. |
| 31 18 53 | P | Roger. Powering down ASCS. |
| 31 18 56 | CC | Cage your gyros. |
| 31 18 57 | P | Roger. They are already caged. |
| 31 19 01 | CC | Gyros caged. ASCS bus turned off. |
| 31 19 04 | P | Roger. |
| 31 19 13 | P | *Would you ask the Cape what do I have left now. I have aux damp, fly-by-wire, and manual proportional; is that affirm, for retrofire? |
| 31 19 46 | CC (CAL) | . . . Com. |
| 31 19 51 | P | Go ahead, Guaymas. |
| 31 19 53 | CC (CAL) | . . . |

| | | |
|---|---|---|
| 31 20 05 | P | Roger. What are they recommending? Do you know? |
| 31 20 11 | P | Roger. |
| 31 20 17 | CC (CAL) | . . . |
| 31 20 21 | P | Roger. |
| 31 20 27 | CC (CAL) | . . . |
| 31 20 31 | P | Roger. No problem. |
| 31 21 10 | CC (CAL) | Gordo. This is your last pass over us. |
| 31 21 15 | P | Roger. I'll see you in a couple of days. |
| 31 21 18 | CC (CAL) | Roger. You're doing an outstanding job. I'm proud of you. |
| 31 21 19 | P | Roger. Thank you, Gus. |
| 31 21 23 | CC (CAL) | Your friends in Mexico say adios. |
| 31 21 25 | P | Roger. Muchas gracias. Muchas gracias. That's French for thank you. |
| 31 21 37 | CC (CAL) | The same. |
| 31 54 25 | P | *Okay. Here I am at 31 54 28, now. Slow drift again in the nighttime. Still having trouble with the cabin—with the suit heat-exchanger dome temp; got control of it here, pretty close. Will fool around with it for about another 2 hours and some odd minutes. |
| 31 55 18 | P | Everything looks good. I have 53 percent auto [fuel] and about 79 percent manual [fuel]. |
| 31 58 20 | P | Okay. |
| 32 20 55 | P | I'm observing some cities through the clouds at 32 20, 32 21. |
| 32 21 17 | P | Seeing out over Laos. |

COASTAL SENTRY QUEBEC (TWENTY-FIRST PASS)

| | | |
|---|---|---|
| 32 22 02 | P | Roger, CSQ Cap Com. Faith Seven here. |
| Unreadable | CC | . . . |
| 32 22 18 | P | Roger, CSQ Cap Com. Faith Seven reading you. |
| 32 22 23 | P | Roger. I read you, John. |
| 32 22 38 | CC | Faith Seven, this is CSQ Cap Com. Answer if you read me on HF. Over. |
| 32 23 01 | P | Roger, CSQ Cap Com. Faith Seven reading you. |
| 32 23 07 | CC | CSQ Cap Com, Roger. We're going to change your clock, Gordo, to keep you from doing it. We have a list to copy here on this retro procedure. Are you ready for clock command? Over. |
| 32 23 16 | P | Roger. Go ahead. |
| 32 23 19 | CC | Command, on. What we're doing is backing your clock off 1 hour. You'll still be able to use minutes and seconds okay for retro. Over. |
| 32 23 27 | P | Okay. |
| 32 23 29 | CC | Okay. Here is the list to copy. Over. |
| 32 23 37 | P | Roger. Go ahead. |
| 32 23 39 | CC | Roger. Also, before we start this, make sure C-band is on for Range Tracker and also T/M. Over. |
| 32 23 46 | P | Roger. C-band and T/M are on. |
| 32 23 55 | CC | Roger. Okay, are you ready to copy? |
| 32 23 58 | P | Roger. Go. |
| 32 24 00 | CC | Roger, number 1 is attitude permission bypass. |
| 32 24 09 | P | Go. |
| 32 24 11 | CC | Attitude permission bypass is number 1. Do you acknowledge? |
| 32 24 14 | P | Roger. I got that. Go ahead. |
| 32 24 16 | CC | Roger. Retrorocket arm switch, manual. |
| 32 24 21 | P | Roger. Got that. |
| 32 24 24 | CC | Roger. Fly-by-wire thrust select switch, high and low. |
| 32 24 32 | P | Roger. Got it. |
| 32 24 33 | CC | Roger. Retrosequence fuse switch, number 2. |
| 32 24 40 | P | Roger. Got it. |

| | | |
|---|---|---|
| 32 24 43 | CC | Roger. Retromanual fuse switch, number 2. |
| 32 24 49 | P | Roger. |
| 32 24 51 | CC | Roger. ASCS a-c bus switch, on. |
| 32 24 54 | P | Roger. |
| 32 24 56 | CC | ASCS 0.05g fuse switch, number 1. |
| 32 25 04 | P | Roger. |
| 32 25 06 | CC | ASCS control switch, select. |
| 32 25 16 | P | Roger. |
| 32 25 18 | CC | Mode select switch, off. |
| 32 25 25 | P | Roger. |
| 32 25 27 | CC | Manual handle, push on. |
| 32 25 34 | P | Roger. |
| 32 25 37 | CC | Roger. That will put you on manual. If you want to go fly-by-wire all you'd have to do is pull the manual handle off and your mode select to fly-by-wire. Roger. |
| 32 25 45 | P | That's affirm. |
| 32 25 46 | CC | Roger, okay. Squib arm will come on at retrofire minus 5 seconds. |
| 32 25 57 | P | Roger. |
| 32 25 59 | CC | Roger. And I will count down to retrofire with the Cape so you can hear. Over. |
| 32 26 04 | P | Roger, and I'll manually use fire retro then. Is that affirmed? |
| 32 26 09 | CC | Roger. The next step is to depress fire retro override; in other words, push the fire button. Over. |
| 32 26 14 | P | Roger. Understand. |
| 32 26 16 | CC | Roger. Now, if you have no retros, you can use as a backup, the following. If there are no retros, the next procedure would be used as a backup. |
| 32 26 26 | P | Okay. |
| 32 26 29 | CC | Hold just a second. What does your clock read now? Over. |
| 32 26 34 | P | Time to retrograde 01 31 50 now. |
| 32 26 40 | CC | Say, your clock setting should read 34 59 52. Over. |
| 32 26 47 | P | Negative. It does not. |
| 32 26 50 | CC | Roger. Did you copy 34 59 52? Over. |
| 32 26 58 | P | Roger. 34 59 52. |
| 32 27 01 | CC | Roger. You can set it yourself after leaving station here. I think we should get the rest of this procedure now. Over. |
| 32 27 06 | P | Roger. |
| 32 27 09 | CC | Roger. If you have no retros, use—if you get no retros—use as backup the following: number 1, retro delay to instant. |
| 32 27 21 | P | Roger. |
| 32 27 22 | CC | Press retrosequence button. |
| 32 27 24 | P | Roger. |
| 32 27 26 | CC | Okay. Some additional precautions. The retrojettison will have to be done manually. |
| 32 27 31 | P | Roger. |
| 32 27 32 | CC | Be sure that you do not arm the retrojettison switch until after the rockets have fired. Over. |
| 32 27 38 | P | Roger. Don't worry. |
| 32 27 39 | CC | Yeah, I'm with you. You'll probably not get a fire retro telelight, but we should get them okay here on the ground. Over. |
| 32 27 47 | P | Roger. |
| 32 27 48 | CC | Okay. Hold your retroattitude until jettison retro. Keep rates as low as possible, maintaining visual reference as aid for low rates; and at your nominal 0.05g time, select reentry mode. |
| 32 28 03 | P | Roger. |
| 32 28 04 | CC | That reentry mode of selection should be at about 34 09 19. |
| 32 28 11 | P | Roger. |
| 32 28 14 | CC | Okay. You'll come up on ASCS, go on auto with ASCS continuous, switch for your 0.05g, and then your reentry. Over. |
| 32 28 26 | P | Roger. |
| 32 28 27 | CC | Okay. That's the whole works now. Also go cabin fan normal now and your cabin control valve to 3.0. Over. |
| 32 28 35 | P | Roger. I already have it on. |
| 32 28 40 | P | What's wrong with reentering on aux damp on the reentry portion. |

| | | |
|---|---|---|
| 32 28 46 | CC | Say again, Gordo. |
| 32 28 48 | P | Never mind, I'm losing you. Let's go UHF. |
| 32 28 51 | CC | Roger. Okay, see if you can get that 34 59 52 set up before you leave our telemetry. Over. |
| 32 28 59 | P | Roger, will do. |
| 32 29 31 | P | Roger. 34 59 52. |
| 32 29 40 | CC | Roger, Faith Seven. I have you at 34+59+52. Over. |
| 32 29 45 | P | That's affirmative. |
| 32 30 09 | CC | Faith Seven, CSQ. If you receive, switch to HF. Over. |
| 32 30 20 | P | Roger. Reading you loud and clear now, John. |
| 32 30 23 | CC | You came back in loud and clear then. We have your clock setting 34 59 52. That's correct. |
| 32 30 29 | P | That is affirmative. |
| 32 30 32 | P | That's 1 hour off, right? |
| 32 30 34 | CC | Say again, Faith Seven. |
| 32 30 36 | P | That's 1 hour beyond, right? |
| 32 30 37 | CC | That's correct. When we count down, we'll use minutes and seconds only. Over. |
| 32 30 42 | P | Okay. |
| 32 30 45 | CC | They'll check you on this—on later in this pass. Over. We should be ready next time around. |
| 32 30 50 | P | Roger. |
| 32 31 04 | P | Is that next time around or the time after that? |
| 32 31 09 | CC | Say again. |
| 32 31 10 | P | Roger. That is the next time around, is it not? |
| 32 31 13 | CC | That is correct; next time around when we see you, I will be firing. |
| 32 31 17 | P | Roger. |
| 32 31 23 | CC | What is your attitude? Are you in drift now, Gordo? |
| 32 31 26 | P | That's affirmative. |

## HAWAII (TWENTY-FIRST PASS)

| | | |
|---|---|---|
| 32 40 42 | CC | Hello Faith Seven, Faith Seven, Hawaii Cap Com. Do you read? |
| 32 40 46 | P | Roger, Hawaii Cap Com, Faith Seven. Loud and clear. |
| 32 40 49 | CC | Roger, Faith Seven, Hawaii Cap Com recommend take a green as for go now and go over your stowage checklist now . . . did you copy? |
| 32 41 03 | P | Roger. I'm practically all stowed right now. |
| 32 41 09 | CC | Say again, Faith Seven. |
| 32 41 11 | P | I'm practically completed with my stowage checklist now. |
| 32 41 15 | CC | Roger. You understand to take green for go, at this time? |
| 32 41 19 | P | To take what? |
| 32 41 21 | CC | Green for go. Take green for go at this time. |
| 32 41 25 | P | Roger, I understand. A green for go, will do. |
| 32 41 31 | CC | Roger. Zanzibar will go over this checklist that you copied from John, and John will help you with the retrofire time. Also do you understand that the time in your clock now is retrofire time +1 hour? You should read at retrofire 01 00 00. |
| 32 41 55 | P | Roger. Understand. |
| 32 41 58 | CC | Roger. What's your $PCO_2$ reading please? |
| 32 42 02 | P | * Roger, $PCO_2$ is about 2½ [mm Hg] now. |
| 32 42 19 | CC | $PCO_2$ is 2.5. Is that right? |
| 32 42 21 | P | That's affirmative. |
| 32 42 48 | CC | Faith Seven, Hawaii Cap Com. |
| 32 42 52 | P | Go ahead, Hawaii. |
| 32 42 56 | CC | We want the retrofire checklist completed over the Atlantic with the exception of your squib switch which you can get at retrofire—5 sec. |
| 32 43 07 | P | Roger. I intend to have it completed before then. |
| 32 43 23 | CC | Seven, Hawaii Cap Com. I'm sure you're familiar with the star pattern you'll be using during the retrofire. |
| 32 43 32 | P | Roger. |
| 32 44 21 | CC | Faith Seven. Hawaii Cap Com. Everything looks good on the ground. You might keep your eye on the $PCO_2$. What is your visor position? |

| | | |
|---|---|---|
| 32 44 29 | P | Roger. My visor is open and I'm breathing off the cabin. |
| 32 44 32 | CC | Roger. |
| 32 44 34 | P | I'm going to emergency rate on my oxygen for a moment just to see if it's the gage, or if it actually is building up a little. |
| 32 44 42 | CC | Roger. Understand emergency flow rate at this time? [Tone noted.] |
| 32 45 03 | P | Roger. It does not seem to be decreasnig on the gage, so it must be the gage error. |
| 32 45 10 | CC | Roger. We're reading an increase on the ground as well. |
| 32 45 23 | P | I'm back on normal oxygen rate. |
| 32 45 27 | CC | Understand, back on normal. |
| 32 45 30 | P | Roger, fans are running. |
| | | [Standby a-c auto warning tone occurs at 33 03 09]$^{T}$ |
| 33 05 43 | P | Well, things are beginning to stack up a little. ASCS inverter is acting up, and my $CO_2$ is building up in the suit. Partial pressure of $O_2$ is decreasing in the cabin. Standby inverter won't come on the line. Other than that, things are fine. |
| | P | All right, I've checked that. |

ZANZIBAR (TWENTY-SECOND PASS)

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|---|---|---|
| 33 33 14 | CC | Faith Seven, this is Zanzibar Cap Com. How do you read? |
| 33 33 18 | P | Roger, Zanzibar. Faith Seven reading you loud and clear. |
| 33 33 21 | CC | Faith Seven, Zanzibar Cap Com. Let's start your checklist here. |
| 33 33 28 | P | Roger, go ahead. |
| 33 33 29 | CC | One item has been added. Verify visor is closed. |
| 33 33 36 | P | *Negative, visor is not closed at the moment; I have a high $CO_2$ rate in suit. |
| 33 33 47 | CC | Item number 1 on the checklist now reads: cage gyro and remain caged throughout reentry. |
| 33 33 58 | P | Roger. I have an item for you. My ASCS a-c inverter has failed; so I will be making a manual reentry. |
| 33 34 09 | CC | ASCS inverter has failed? |
| 33 34 12 | P | That is affirmative. |
| 33 34 14 | CC | Roger. Let's continue this checklist now. Attitude permission bypass, bypass position. |
| 33 34 21 | P | *Roger. Bypass. |
| 33 34 23 | CC | Retrorocket arm switch manual? |
| 33 34 26 | P | Roger, on manual. |
| 33 34 28 | CC | *Fly-by-wire thrust selector switch, high-low. |
| 33 34 34 | P | Roger on high and low. |
| 33 34 36 | CC | Retrosequence fuse switch number 2. |
| 33 34 39 | P | Number 2. |
| 33 34 42 | CC | Retromanual fuse switch number 2. |
| 33 34 46 | P | Number 2. |
| 33 34 47 | CC | ASCS bus switch on. |
| 33 34 51 | P | ASCS a-c bus is off. |
| 33 34 53 | CC | Roger. ASCS 0.05g fuse switch to number 1 position. |
| 33 34 59 | P | On number 1. |
| 33 35 01 | CC | ASCS control switch select. |
| 33 35 04 | P | On Select. |
| 33 35 07 | CC | Mode select switch off. |
| 33 35 08 | P | Mode select off. |
| 33 35 11 | CC | Manual handle push on. |
| 33 35 14 | P | Manual handle is on. |
| 33 35 16 | CC | *Right. Squib arm at retro minus 5 seconds. |
| 33 35 27 | P | Roger. |
| 33 35 28 | CC | And that will occur in approximately 25 minutes. |
| 33 35 31 | P | Roger, I understand. |
| 33 35 35 | CC | Have you tried the standby inverter on ASCS bus? |
| 33 35 38 | P | Roger, the standby inverter will not start. |
| 33 35 41 | CC | The standby inverter will not start. |
| 33 35 43 | P | That is affirmative. |
| 33 35 45 | CC | Roger. Cape Flight advises you believe your $CO_2$ partial gauge in the capsule, as this was confirmed over Hawaii. |
| 33 36 05 | P | Cape advises what? |

| | | |
|---|---|---|
| 33 36 09 | CC | We will advise you at this time. You have sufficient oxygen in to continue on emergency rate from now through reentry if required. |
| 33 36 17 | P | Ah, Roger. I understand. |
| 33 36 22 | CC | Shall we go over the retro backup? |
| 33 36 26 | P | Negative. I have that straight. I'll just go to retrofire to instantaneous and punch retrosequence. |
| 33 36 35 | CC | That is correct. You have the other additional precautions. |
| 33 36 47 | P | Negative. What's that? |
| 33 36 48 | CC | Retrojettison must be done manually. |
| 33 36 52 | P | Oh, roger, roger. I have those. |
| 33 36 53 | CC | Retrojettison switch to arm, after rockets fired. |
| 33 36 58 | P | Roger. I have that. |
| 33 37 03 | CC | You will probably not get a fire retro telelight. |
| 33 37 06 | P | Roger. |
| 33 37 08 | CC | Ground should be able to confirm, though. |
| 33 37 11 | P | Roger. |
| 33 37 31 | CC | Faith Seven, Zanzibar Cap Com. |
| 33 37 34 | P | Go ahead Zanzibar, Faith Seven. |
| 33 37 36 | CC | *We've had about 3-percent rise on the $CO_2$ partial. Do you think it is advisable to purge again at this time? |
| 33 37 47 | P | Negative. It seems to be holding pretty steady over what it has been. |
| 33 37 51 | CC | Roger. We're getting very poor air-ground communications at this time. |
| 33 37 56 | P | Roger. |
| 33 38 09 | CC | . . . Faith Seven. Zanzibar Cap Com. |
| 33 38 12 | P | Go ahead, Zanzibar. Faith Seven. |
| 33 38 14 | CC | We would advise the visor be closed prior to retrofire. |
| 33 38 20 | P | Roger, it will be. |
| 33 38 35 | CC | Faith Seven, Zanzibar Cap Com. |
| 33 38 38 | P | Go ahead. |
| 33 38 39 | CC | Cape advises closing visor. |
| 33 38 42 | P | Roger. |
| 33 38 44 | CC | Do you confirm. |
| 33 38 46 | P | Roger. Will close visor. Visor is closed and locked. |
| 33 39 02 | CC | Roger, visor is closed and locked. Continue to watch that $PCO_2$ meter and if it rises, go on emergency rate. |
| 33 39 10 | P | Roger. |

COASTAL SENTRY QUEBEC (TWENTY-SECOND PASS)

| | | |
|---|---|---|
| 33 56 25 | P | CSQ Cap Com, Faith Seven. Over. |
| 33 57 03 | CC | Hello, Faith Seven, CSQ Cap Com. Over. |
| 33 57 06 | P | Roger, CSQ Cap Com. Faith Seven in retroattitude. Checklist complete. |
| 33 57 16 | P | Roger, CSQ Cap Com, Faith Seven. |
| 33 57 19 | CC | Faith Seven, CSQ Cap Com. Roger. You're sounding good. How's that check test? All complete? |
| 33 57 24 | P | Roger. All complete except for squib. |
| 33 57 26 | CC | Roger. How's the window attitude? Check okay? |
| 33 57 30 | P | Roger. Right on the old gazoo. |
| 33 57 32 | CC | That's the way, boy. |
| 33 57 34 | CC | *Okay. Our procedure, Gordo. I'll give you the 1-minute hack before retrofire and then I'll give you a 10-second countdown to what would normally be retrosequence. This time there will just be a countdown to a 30-second point and then a 10-second countdown to retrofire and at the 5 point tell you to arm squib. |
| 33 57 53 | P | Roger. That's fine. |
| 33 57 54 | CC | Roger. |
| 33 57 59 | CC | How's your $PCO_2$ doing? |
| 33 58 02 | P | Oh, its coming on up. And my ASCS inverter has failed, few other little odds and ends. |
| 33 58 09 | CC | Okay. Roger. |
| 33 58 11 | P | *I'll shoot the retros on manual, and I'll reenter on fly-by-wire. |
| 33 58 18 | CC | Roger. Okay. |

| | | |
|---|---|---|
| 33 58 20 | P | I'm looking for a lot of experience on this flight. |
| 33 58 23 | CC | You're going to get it. |
| 33 58 26 | CC | Okay, we've got the beginning of the 1-minute period and about 25 seconds here. |
| 33 58 31 | P | Roger. |
| 33 58 48 | CC | Okay. One minute to go on my mark. Stand by. |
| 33 58 54 | CC | MARK. [33 58 54]$^{T}$ |
| 33 59 00 | CC | Did you get that? |
| 33 59 03 | P | Roger. I got it. |
| 33 59 04 | CC | Roger. I'll give you a 10-second count here down to the 30-second point. |
| 33 59 08 | P | Roger. |
| 33 59 14 | CC | 10, 9, 8, 7, 6, 5, 4, 3, 2, 1. Thirty [33 59 24]$^{T}$ seconds. |
| 33 59 30 | CC | Okay. The next 10-second count will be a countdown to your manual retro. Over. |
| 33 59 35 | P | Roger. |
| 33 59 44 | CC | 10, 9, 8, 7, 6, squib arm. 4, 3, 2, 1, fire [33 59 53]$^{T}$. Roger. A green one here. |
| 34 00 13 | P | Roger. I think I got all three. |
| 34 00 16 | CC | Roger. How did your attitude hold, Gordo? |
| 34 00 18 | P | Well, pretty fine. |
| 34 00 20 | CC | Good show, boy, real fine. Looks like they came off right on the money on time. |
| 34 00 25 | P | Roger, I think so. |
| 34 00 28 | CC | *Roger. Very good. On the next mark at 60 seconds from that retro, you should jettison retros; and you'll do that one manually, right? |
| 34 00 37 | P | Roger. |
| 34 00 40 | CC | Got any estimate on your attitude hold, in any axis how far you drifted off on retro? Over. |
| 34 00 45 | P | No, I sure don't. I held it relatively close, John, but I couldn't guess. |
| 34 00 52 | CC | That's the way to do it. Just too close to tell any error. Good head. |
| 34 00 55 | P | Ha, ha. No, I wouldn't say that. |
| 34 00 59 | CC | Roger. You can go ahead and jettison retros and time. |
| 34 01 01 | P | Roger. Jettisoning retros. |
| 34 01 09 | P | And off they came. |
| 34 01 14 | CC | We have your signal. |
| 34 01 17 | P | Roger. |
| 34 01 18 | CC | *Okay. Dealers choice on reentry here, fly-by-wire or manual. I think you said, you're coming back in fly-by-wire? |
| 34 01 28 | P | Roger. I think I'll come back in fly-by-wire. |
| 34 01 31 | CC | Roger, okay. You can hold retroattitude now for a while here. If you wanted to hold your attitude more close by holding retroattitude until you get a little closer to 0.05g. |
| 34 01 43 | CC | Your 0.05g is 34 09 19. Just before you get to that, you can come up to your zero reentry attitude. Over. |
| 34 01 51 | P | Roger. |
| 34 01 53 | CC | And you can establish roll at that time also. |
| 34 01 56 | P | Roger. |
| 34 02 01 | P | *What was the time on establishing that? |
| 34 02 06 | CC | *34 09 19. That is your 0.05g time. |
| 34 02 11 | P | Roger. |
| 34 02 14 | CC | Just a little bit before that you could come on up to zero zero. |
| 34 02 20 | P | Roger. |
| 34 02 31 | CC | Roger. Keep your rates down, keep your rates as near zero as you can. |
| 34 02 36 | P | Roger. Will do. |
| 34 02 49 | CC | *It's been a real fine flight, Gordo. Real beautiful all the way. Have a cool reentry, will you? |
| 34 02 55 | P | Roger, John. Thank you. |
| 34 03 24 | CC | Faith Seven, CSQ. |
| 34 03 27 | P | Roger, CSQ. |
| 34 03 28 | CC | ASCS 0.05g switch fuse to the off position. Over. |
| 34 03 33 | P | Roger. 0.05g switch fuse to the off position. |
| 34 03 37 | CC | Roger. |
| 34 03 42 | P | Roger. |

RANGE TRACKING SHIP (TWENTY-SECOND PASS)

| | | |
|---|---|---|
| 34 08 21 | CC | Faith Seven, Faith Seven, Faith Seven, this is RTK M and O [Maintenance and Operations]. How copy? |
| 34 08 27 | P | Roger, Faith Seven. Reading you loud and clear. |
| 34 08 30 | CC | * Roger, RTK here. I have landing area weather for you. Ready to copy? |
| 34 08 34 | P | Roger. |

HAWAII (TWENTY-SECOND PASS)

| | | |
|---|---|---|
| 34 13 07 | CC | Faith Seven, Faith Seven, Hawaii Cap Com. Do you read? |
| 34 13 11 | P | Roger. |
| 34 13 13 | CC | Faith Seven. What is your status? |
| 34 13 16 | P | Roger. Doing fine. |
| 34 13 21 | CC | Faith Seven, Hawaii Cap Com. Say your status. Over. |
| 34 13 25 | P | Roger. Faith Seven is doing fine. Reentering. |
| 34 13 29 | CC | Roger. Is your altimeter off the peg yet? Over. |
| 34 13 33 | P | Roger. |
| 34 13 36 | CC | Say your altitude; say your altitude. |
| 34 13 38 | P | Roger, 95,000 [feet]. |
| 34 13 43 | CC | Roger. Understand 85. Are you standing by for the drogue at 40,000 [feet]? |
| 34 13 49 | P | Roger. |
| 34 13 50 | CC | We have tops of cloud in recovery area at about 36,000 feet. |
| 34 13 58 | CC | There is a 0.5 cloud coverage at 1,500 feet. 5- to 6 foot waves. Surface wind, 15 knots from 085 degrees. Stand by for your recovery time. Did you copy? |
| 34 14 15 | P | Roger, you'll have to wait a minute, I'm just hanging on here now. |
| 34 14 21 | CC | Roger, Faith Seven. Say again your last. |
| 34 14 31 | P | I got a drogue. |
| 34 14 34 | CC | Understand, drogue is out. |
| 34 14 35 | P | Roger. |
| 34 14 42 | CC | *Think I got a—an oral report of drogue out. Stand by. |
| 34 14 52 | CC | Faith Seven, Hawaii Cap Com. Is your drogue out at this time? |
| 34 14 55 | P | Roger, drogue is out. |
| 34 14 59 | CC | Checklist follows. Snorkel ring at 20,000 feet. Landing-bag switch to auto. Recovery arm switch, manual. Fuel jettison fuse switch, number 1. Fuel cross-feed handle, push on. Roll, yaw, pitch, T-handles push on. Position the T/M switch, your option. ASCS select switch should be off. And give me the status on your fuel dump. Over. |
| 34 15 47 | P | Fuel is dumped.[2] |
| 34 15 50 | CC | Understand fuel is dumped. Pressure regulator handle should be pulled. |
| 34 16 03 | P | Roger. I have a good main. |
| 34 16 07 | CC | Say again, Faith Seven. |
| 34 16 09 | P | Roger, I have a good main chute. |
| 34 16 11 | CC | Good main chute, good show. |
| 34 16 14 | P | Roger, landing bag is down and green. |
| 34 16 15 | CC | Repeat, please? |
| 34 16 16 | P | Landing bag is down and green. |
| 34 16 17 | CC | Understand the landing bag is green. What is your rate of descent? |
| 34 16 28 | P | About 34 feet per second. |
| 34 16 31 | CC | Everything looks good, preparation for impact. Urine transfer shutoff valve closed. Transfer hose, disconnect. Blood pressure hose, disconnect. Aeromed connector, disconnect. Helmet outlet hose, disconnect. |
| 34 16 59 | CC | Faith, are you staying with me, Gordo? |
| 34 17 02 | P | Roger, I've got my list right here, Scott. |
| 34 17 06 | CC | Say again, Gordo. |
| 34 17 11 | CC | Roger, helmet should be unlocked and opened. |
| 34 17 19 | CC | Temperature probe should be disconnected. |
| 34 17 24 | CC | Unfasten your helmet neck-ring seal. |
| 34 17 31 | CC | Tighten your straps. |
| 34 17 36 | CC | Lock the shoulder reel harness. |
| 34 17 41 | CC | Stand by for impact. |
| 34 17 45 | P | Roger. |

[2] Pilot subsequently informed editor that he meant to say "fuel dump is armed." The rapidity of events at this moment precluded his rendition of a corrective statement to Cap Com.

| | | |
|---|---|---|
| 34 17 47 | CC | Are there any recovery aircraft on air-to-ground now? |
| 34 17 52 | P | Negative. |
| 34 17 56 | CC | This is Hawaii Cap Com. Understand you are in communication with recovery aircraft, is that correct? |
| 34 18 02 | P | Negative. Negative, I am not. Over. |
| 34 18 09 | CC | We'll stay with you then. |
| 34 18 19 | CC | Seven, Hawaii Cap Com. [*USS*] *Kearsarge* has visual contact with you at this time, over. |
| 34 18 25 | P | Roger, thank you. That sounds good. |
| 34 18 29 | CC | Good show, pal. |
| 34 18 43 | CC | Faith Seven, Hawaii Cap Com. Say your altitude. |
| 34 18 47 | P | Roger. 4,000 feet. |
| 34 18 49 | CC | 4,000, your preimpact check is complete. Is that correct? |
| 34 18 53 | P | Roger. |
| 34 18 55 | CC | Understand preimpact checklist is complete. |
| 34 19 00 | P | Roger. Fuel is jettisoned and all T-handles are in. |

RECOVERY (TWENTY-SECOND PASS)

| | | |
|---|---|---|
| 34 19 04 | R1 | Hello Astro. This is 1 Indian Gal. Over. |
| 34 19 07 | P | Roger, this is Astro. Go ahead. |
| 34 19 10 | R1 | Roger, 1 Indian Gal. We are circling you at about 500 feet; you're coming down very nicely. Sea state is about 5- to 8-foot waves, a few white caps. Wind is just perfect for a helo [helicopter] operation. The carrier [*USS Kearsarge*] is about 5 miles away. |
| 34 19 31 | P | Roger. |
| 34 19 42 | R1 | Astro, you are swaying just a little bit, looks like about a 50 or rather, correction, a 30-foot sway. You're coming down very nicely. You are presently about 1,000 feet. The wind is from the southwest at about 12 knots, perhaps 15. |
| 34 20 06 | P | Roger, understand. |
| 34 20 14 | R1 | Astro, 1 Indian Gal. How do you feel? Over. |
| 34 20 17 | P | Roger, I'm in fine shape. Excellent. |
| 34 20 22 | R1 | Thank you Astro. This is Indian Gal. We still are circling you very nicely. You're now steadying up quite nicely, about 400 feet. You are passing my starboard side. |
| 34 20 35 | P | Roger. |
| 34 20 36 | R1 | Have three helos right around you. Got the swimmers with me. They'll be out just about the time you're setting down on the water. |
| 34 20 44 | P | Roger. |
| 34 20 47 | R1 | The carrier is only about 3 miles away. Couldn't be a nicer shot. |
| 34 20 50 | P | But I missed that third elevator. |
| 34 20 53 | R1 | Now you are in the water in good shape. |
| 34 20 57 | R1 | Your parachute is still with you. Chute has spilled and is in the water. |
| 34 21 09 | R1 | Collar in the water. |
| 34 21 15 | P | Roger. |
| 34 21 23 | R1 | Your dye markers out now, Astro. Looks nice. I'm coming in now for the swimmers. |
| 34 21 39 | R1 | Astro, your capsule is on the side. The capsule parachute did not deploy. |
| 34 21 46 | P | Roger. |
| 34 21 49 | R1 | Now your capsule is coming up nicely. It's sitting at about a 30-degree angle on the water. |
| 34 21 55 | P | Okay. |
| 34 21 56 | R1 | You look pretty good. |
| 34 22 02 | R1 | I'm on top over you, directly overhead. Your capsule is now erected nicely. You're bouncing on the sea. I notice now that the parachute has released. I'm now going to drop the swimmers. |
| 34 22 14 | P | Roger. Hold them clear a minute and I'll get the HF antenna up. |
| 34 22 38 | K | Astro, from Begonia on *Kearsarge*. How do you read me? Over. |
| 34 22 43 | P | Roger, Begonia, Faith Seven. Read you loud and clear. Over. |
| 34 22 47 | K | Roger, how you feeling? Over. |
| 34 22 50 | P | Fine, couldn't be better. |
| 34 22 52 | R1 | Astro, all the swimmers are out. The first one is on your capsule now. He's pounding. Do you hear him? Over. |
| 34 22 57 | P | Roger, good shape. [Shouting to swimmers.] |
| 34 23 13 | P | Hello dahr, how are you? [Shouting to swimmers.] |

| | | |
|---|---|---|
| 34 23 17 | K | Gordon, this is Begonia. We estimate approximately 45 minutes to have you on deck on *Kearsarge*. Please advise your wishes and any info this subject. Over. |
| 34 23 33 | P | *I'm okay. I'll wait on the boat.* [*Shouting to swimmers.*] |
| 34 23 37 | P | I'm in good shape. |
| | | *[Nonflight-related transmission omitted.] |
| 34 23 45 | R1 | Astro, this is 1 Indian Gal. Do you hear the swimmers? Over. |
| 34 23 52 | P | I just had my helmet off talking to the swimmers. |
| 34 23 54 | R1 | Roger. I see you don't have smoke. Apparently, you are all right. What is—Begonia desires to know—what your desires about being picked up. Over. |
| 34 24 02 | P | Roger. I'd like to come aboard the carrier if they will grant me permission for an Air Force troop. |
| 34 24 06 | R1 | *Roger. Begonia, this is 1 Indian Gal. Gordon Cooper desires to come on board the carrier if they will let an Air Force Officer aboard. Over. |
| 34 24 18 | K | Roger. Permission granted, of course, and I don't know whether he heard me before or not. Estimate about 45 minutes to have him on deck. Over. |
| 34 24 30 | R1 | *Major, Begonia estimates 45 minutes for your on-deck time. What are your desires? Over. |
| 34 24 37 | P | Roger. I'll wait to go on board. Over. |
| 34 24 40 | R1 | Roger, understand that you desire pickup by Wildcat . . . . |
| 34 24 44 | P | Thank you, sir. No, negative. I'll wait and go on board the carrier. Begonia did you read? Over. |
| 34 24 47 | R1 | Roger. I understand you will be hoisted by the carrier. Begonia did you read? Over. |
| 34 24 53 | K | This is Begona. I copy. Out. |
| 34 25 00 | K | Indian Gal 1, Begonia. What status on collar? Over. |
| 34 25 05 | R1 | Roger, collar is about half way around. The swimmers are in the water nicely. The capsule is working well. |
| 34 25 12 | K | Roger. |
| 34 25 14 | R1 | The parachute was a little delayed in deploying. It it now riding very nicely in the water. |
| 34 25 26 | ? | Roger, Wildcat, Tea Kettle 222. Go . . . . |
| 34 25 31 | R1 | *They attached the collar just about all the way around. The sea state is the same as the ship. |
| 34 25 39 | R1 | *The collar—the capsule looks like it's riding at about a 20-degree angle. Quite steady in the water.* |
| 34 26 13 | R2 | One from two. |
| 34 26 15 | R1 | One. Over. |
| 34 26 16 | R2 | *Roger. Swimmers desire to save chute. Shall I deploy swimmers? Over. |
| 34 26 20 | R1 | *This is one. Don't deploy swimmers at this time. The boat looks like it will pick up the chute. It is close enough. |
| 34 26 29 | R2 | Roger. |
| 34 26 30 | R1 | Wildcat, the collar now looks like it is all the way around the capsule. It's just about to be inflated. |
| 34 26 37 | R1 | The swimmers are still with it. The chute is still floating next to the capsule. They don't look like they are having any difficulty. Looks like a normal operation. |
| 34 26 49 | K | This is Begonia. Roger, out. |
| 34 26 52 | R1 | *The collar is now inflated fully. |
| 34 26 56 | R1 | It has picked the capsule up nicely. It is now erect, and the swimmers are making final adjustments. |
| 34 27 06 | K | Begonia. Roger, out. |
| 34 27 08 | P | Sorry, I missed that third elevator, Begonia. |
| 34 27 12 | R1 | *Begonia, Gordon Cooper says he's sorry he missed the third elevator.* |
| 34 27 18 | K | I think it's a quite acceptable shot, Major. |
| 34 27 25 | P | Thank you. |
| 34 27 33 | R1 | Begonia, the swimmers are now hanging on to the collar. It is fully inflated; the capsule is upright. The capsule looks like it's riding very nicely in the water, just going up and down slightly on the 5- to 8-foot waves. There are a few white caps around, but they are not breaking over the tower. |
| 34 27 57 | R1 | Looks like a normal operation, and they are just waiting for him. |

| | | |
|---|---|---|
| 34 28 07 | K | * This is Begonia. Gordon, are you in communication with the swimmers at this time? Over. |
| 34 28 14 | P | I can yell to them through the hatch here. |
| 34 28 18 | K | I understand that you can hear them through the hatch. Is that correct? |
| 34 28 21 | P | Roger, we can communicate by yelling back and forth, I believe. |
| 34 28 26 | K | Roger. Out. |
| 34 28 42 | K | Major Cooper, from the USS *Kearsarge*, welcome to the Pacific. Good landing. |
| 34 29 01 | R1 | *Major, the *Kearsarge* is now making a down base leg. They are going to make a normal 180 approach to you. They are about 2 miles away coming down wind. They will start their turn into your position in about 10 minutes. |
| 34 29 17 | P | Roger. Very fine. |
| 34 29 19 | P | Hello. How are you doing? I'm fine. Okay. How aré you? [Shouting to swimmers.] |
| 34 29 36 | K | Major, they estimate your miss at 3,900 yards. Looks like a record. |
| 34 29 43 | P | Say again, sir. Say again, I was talking to the swimmers. |
| 34 29 47 | K | Roger. You missed by 3,900 yards, very acceptable. |
| 34 29 51 | P | Thank you. |
| 34 29 54 | P | What? I'll wait on the carrier. What? [To swimmers.] |
| 34 30 05 | R1 | Two, this is One. Looks like the parachute is sunk now, I don't see it anymore. There is a small drogue chute still . . . upwind of the green dye. |
| 34 30 15 | K | Delighted to have you back in the Pacific and congratulations on a wonderful, wonderful ride. |
| 34 30 23 | P | What? Yeah, I'll wait on the carrier. [To swimmers.] |
| 34 30 32 | K | Gordon, this is Begonia. John Graham will be on this line and be stationed down near the hangar—near the elevator—about the time that we pick you up. Thought I would alert you that he will be on the line to talk to you just before you get out. Over. |
| 34 30 52 | P | Roger. Fine. |
| 34 31 00 | K | Is there anything we can do in preparation . . . . |

## ACKNOWLEDGEMENT

During the life of the Mercury Project, several million people have unselfishly contributed their knowledge, skill, and ingenuity to make this pioneering space project a successful national effort. The people came from all walks of life; they came from government agencies, from industrial organizations, and from many educational institutions. Also, valuable cooperation has been received from a number of people and governments of other nations to enable the accomplishment of the essential support activities around the earth. Each person is to be commended for his untiring efforts and his unfaltering faith in the ultimate successful fulfillment of the objectives of the project.

ROBERT R. GILRUTH
*Director*

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Edited by

James P. Henry, M.D., Ph.D. and John D. Mosely, D.V.M., eds.

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# FOREWORD

This publication presents a full account of the flights of the Project Mercury chimpanzees, from program planning through launch and recovery operations. A detailed account of training techniques, in-flight measurements, and post-flight evaluation procedures is given. The suborbital ballistic flight of "Ham" on January 31, 1961, was the prelude to Alan B. Shepard's suborbital space flight, while the orbital flight of "Enos" on November 29, 1961, preceded the flight of Astronaut John H. Glenn.

The fact that we now categorize these events as belonging to the rather distant past, although they occurred only about two years ago, serves to emphasize the pace of development in the exploration of space. While the chimpanzee program may pale in the light of subsequent successes, its scientific and technological contribution should not be overlooked.

The significance of this project can be fully appreciated, and its contribution judged, only within the context of knowledge existing at the time of its conception. In addition to its essential training function, it verified the feasibility of manned space flight through operational tests of the Mercury life-support system. It demonstrated that complex behavioral processes and basic physiological functions remained essentially unperturbed during brief exposures to space flight. The Mercury Chimpanzee Program marked the first time that physiological and behavioral assessment techniques were combined for evaluating the functional efficiency of the total organism in space.

Perhaps the ultimate contribution of this program, however, was in providing the technological framework of knowledge upon which future scientific experiments on biological organisms, exposed to flights of extended durations, must be based. Biosatellite experiments designed to seek more subtle and elusive effects of prolonged space flight on biological functioning will require even more refined and difficult techniques, but will depend heavily on the technological groundwork laid in these early steps of Project Mercury.

RICHARD E. BELLEVILLE
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*Bioscience Programs*
*Office of Space Sciences*

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# PREFACE

This document presents a compilation of papers reporting the results of the ballistic, or Mercury-Redstone 2 (MR–2), flight and of the orbital, or Mercury-Atlas 5 (MA–5), flight conducted with chimpanzees as subjects by the Manned Spacecraft Center of the National Aeronautics and Space Administration. The MR–2 flight with the chimpanzee "Ham," as a subject was conducted on January 31, 1961; and the MA–5 flight with the chimpanzee "Enos," as a subject was conducted on November 29, 1961. In both of these flights, the animals were handled in accordance with the "Principles of Laboratory Animal Care" established by the National Society for Medical Research.

# 1. SYNOPSIS OF THE RESULTS *of the* MR–2 AND MA–5 FLIGHTS

By James P. Henry, M.D., Ph. D.*

In April 1959, an animal test program with the following objectives was established for Project Mercury:

(1) Provision of animal verification of a successful space flight prior to manned flight.

(2) Provision of data on the physical and psychological demands which were to be encountered by the astronauts during space flight.

(3) Provision of a dynamic test of operational procedures and training of support personnel in handling the biomedical program for manned flight.

(4) Evaluation of the spacecraft environmental control system and bioinstrumentation under flight conditions.

The three sensory modalities most concerned with the weightless state are: vision, proprioception, and the labyrinth. Of these, it is primarily the otoliths in the labyrinth that lose their normal input during the weightless state. The tests were performed during the Mercury animal flights to ascertain whether the restrained animal, retaining visual and kinesthetic references, could respond normally during weightlessness to a series of problems graded in difficulty and in motivation. The animal was trained to respond on a schedule that involved mild punishment for error. In addition, a reward system, in the form of food pellets and drinks of water, was provided. The purpose of the schedule was both to determine whether there was a loss of appetite for food or water and, also, to establish that eating and drinking could be carried out normally in the weightless state. The bioinstrumentation resembled, as closely as possible, that used in the human Mercury flights for which these animal flights were to be introductions. One important addition for the MA–5 flight was the use of a special instrumentation package by which onboard recordings would be made from both the low (venous) and high-pressure (arterial) systems of the circulation before and during flight.

The comprehensive series of operant tasks involving both reward and avoidance was based primarily on the principles and techniques established by Skinner, Ferster (refs. 1 and 2), and Sidman (refs. 3 and 4). Originally, the feasibility of applying such techniques—which had already been worked out for the pigeon, rat and monkey—to the chimpanzee was problematical since previous operant studies of these animals had not used avoidance conditioning. It is one of the accomplishments of the animal program that solutions to the various problems in comparative psychology were so rapidly found and that a highly effective and complex series of in-flight tasks was developed and successfully used in space.

## Methods

The techniques employed to adapt the chimpanzee to the Mercury spacecraft, the methods by which the operations of preparing the animal and delivering him in the ready state to the gantry at launch time were carried out, and a medical account of prelaunch preparations and recovery and postrecovery care are presented in this report.

## Results

Results are also presented in the body of the report. They show that:

(1). Pulse and respiration rates, during both the ballistic (MR–2) and the orbital (MA–5) flights, remained within normal limits throughout the weightless state. Effectiveness of heart action, as evaluated from the electrocardiograms and pressure records, was also unaffected by the flights.

(2) Blood pressures, in both the systemic arterial tree and the low-pressure system, were not signifi-

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cantly changed from preflight values during 3 hours of the weightless state.

(3) Performance of a series of tasks involving continuous and discrete avoidance, fixed ratio responses for food reward, delayed response for a fluid reward, and solution of a simple oddity problem, was unaffected by the weightless state.

(4) Animals trained in the laboratory to perform during the simulated acceleration, noise, and vibration of launch and reentry were able to maintain performance throughout an actual flight.

## Conclusions

From the results of the MR–2 and MA–5 flights, the following conclusions were drawn:

(1) The numerous objectives of the Mercury animal test program were met. The MR–2 and MA–5 tests preceded the first ballistic and orbital manned flights, respectively, and provided valuable training in countdown procedures and range monitoring and recovery techniques. The bioinstrumentation was effectively tested and the adequacy of the environmental control system was demonstrated.

(2) A 7-minute (MR–2) and a 3-hour (MA–5) exposure to the weightless state were experienced by the subjects in the context of an experimental design which left visual and tactile references unimpaired. There was no significant change in the animal's physiological state or performance as measured during a series of tasks of graded motivation and difficulty.

(3) The results met program objectives by answering questions concerning the physical and mental demands that the astronauts would encounter during space flight and by showing that these demands would not be excessive.

(4) An incidental gain from the program was the demonstration that the young chimpanzee can be trained to be a highly reliable subject for space-flight studies.

## References


1. Skinner, B. F.: The Behavior of Organisms. Appleton-Century-Croft (New York), 1938.
2. Ferster, C. B., and Skinner, B. F.: Schedules of Reinforcement. Appleton-Century-Croft (New York), 1957.
3. Sidman, Murry: Avoidance Conditioning with Brief Shocks and No Exteroceptive Warning Signal. Science, vol. 118, no. 3057, 1953, pp. 157–158.
4. Sidman, Murry: Time Discrimination and Behavioral Interaction in a Free Operant Situation. Journal of Comparative and Physiological Psychology, vol. 49, 1956, pp. 469–473.

# 2. ANTECEDENTS AND PLANNING ASPECTS *of the* MR–2 FLIGHT

By James P. Henry, M.D., Ph. D.,* and
John D. Mosely, D.V.M.**

Experimental bioastronautics began with the use of animals in the late 1940's and evolved in an atmosphere of sharp distinction from aviation medicine in which animals have been used mainly for on-the-ground support research. A number of ballistic flights with animals were accomplished with encouraging results during the period from 1948 to 1958. In 1959, with the initiation of the Mercury man-in-space program it was decided by the National Aeronautics and Space Administration that animals should be employed to test the adequacy of the various systems used to support life. The intention was not to make extensive physiological studies of the effects of the weightless state, but rather to use animals to ensure the adequacy of the life-support systems.

## Little Joe Flight

The first step in the attempt at animal verification of the adequacy of the Mercury flight program was the development of two tests in collaboration with the U.S. Air Force School of Aviation Medicine in which there would be a biomedical evaluation of the accelerations expected during the abort of a Mercury flight at lift-off and shortly after lift-off. These flights were to be launched at the NASA Wallops Station with a "Little Joe" solid-fuel launch vehicle.

Two Little Joe firings were made with activation of the escape rockets during the boost phase to secure maximum acceleration, and only a brief period of weightlessness was attained. The first firing was on December 4, 1959, and the other on January 21, 1960. A 36- by 18-inch sealed, 125-pound, cylindrical capsule containing the subject, an 8-pound *Macaca mulatta* (monkey), the necessary life support system and associated instrumentation was flown in a "boiler plate" model of the Mercury spacecraft. A detailed report was prepared by the U.S. Air Force School of Aerospace Medicine. (See ref. 1.)

## Chimpanzee Flight Program Planning

Immediately following initiation of the Little Joe biopack program, a meeting was held at NASA Manned Spacecraft Center on April 13 and 14, 1959, to plan a further series of flight tests of full-scale spacecraft containing animals in which observations could be made of the effects of long-range ballistic and orbital flights. The purposes of these studies were:

(1) To provide animal verification of the feasibility of a manned flight.

(2) To provide data on the level of mental and physical activity which could be expected during the flight.

(3) To provide a dynamic test of countdown procedures and training of support personnel in handling the biological aspects of manned flight.

The above mentioned planning group was composed of representatives of the McDonnell Aircraft Company, NASA Manned Spacecraft Center, and Navy, Army, and Air Force biomedical specialists. It was agreed that the existing Mercury spacecraft life support, environmental control, and instrumentation systems should be used without modification in all tests. The 6571st Aeromedical Research Laboratory at Holloman Air Force Base was assigned the responsibility for the training of the animals, their preparation for the flight, and their handling after recovery. A Manned Spacecraft Center representative was assigned as coordinator to insure integration of animal flights into the overall flight program and to insure cooperation of all organizations required to support the program. In order to provide the highest level of performance short of a human, it was decided that

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chimpanzees should be used because of their size and physical similarity to man. Restraint would be minimal to permit performance of psychomotor tests. The electrocardiogram, body temperature, and respiratory movements would be recorded by the same techniques as those used for the man. If possible, arterial pressure would be recorded. Urine would be saved for a study of steroid output and there would be photography of the subject. At that time, it was decided that various types of performance would be required of the subjects to simulate the tasks of the human operator. They would involve simple motor movements of the arms and hands, discriminations of visual signals, and acts requiring judgment. In the longer orbital flight, the difficulty of the task would be raised to a level that would approximate the man's task as closely as possible within the animals' capability. The effect of the flights upon the animals' performance would be measured during flight and would be determined by preflight and postflight studies.

The three military services of the Department of Defense accepted the Manned Spacecraft Center's position and further agreed that all services would support the Aeromedical Research Laboratory insofar as practical.

Although the Aeromedical Research Laboratory (AMRL) had animals, veterinarians, and space physiologists, it had, at that time, no facilities to obtain behavioral measurements of these animals; therefore, several chimpanzees were trained under a contract with the Wenner-Gren Aeronautical Research Laboratory, University of Kentucky. In addition, the Air Force transferred, to the AMRL in whole, the animal performance facility and personnel of the Unusual Environments Section, Aerospace Medical Laboratory, Aerospace Systems Division, Dayton, Ohio. Before this group arrived in August 1959, arrangements were made with the Walter Reed Army Institute of Research to aid the preliminary establishment of the Comparative Psychology Branch at AMRL. As soon as possible after the establishment of the Comparative Psychology Branch, the training of eight chimpanzees began with the use of standard operant conditioning equipment and special restraint chairs.

## Development Phases

Soon after assignment of the animal program to the Aeromedical Research Laboratory, the Laboratory began a series of meetings with representatives of the Manned Spacecraft Center and the McDonnell Aircraft Corporation. The first hurdle was to provide environmental support for the chimpanzee subject in the Project Mercury spacecraft. There are two loops in the environmental control system, one for the spacecraft cabin, and one for the astronaut pressure suit. The NASA decision was to use the chimpanzee to evaluate the suit environmental control loop. With this decision, it was feasible to design a couch to fit the chimpanzee and put a cover on this couch which then could be sealed. This simulated the astronaut pressure suit with the faceplate closed. (See figs. 2–1 and 2–2.) The details of the psychomotor apparatus are discussed in section 4 of this series of papers. Of great importance is the fact that, in keeping with the policy of noninterference with the Mercury spacecraft, in the final design the programing apparatus was to be completely within the chimpanzee couch and to require from the spacecraft system only the power for its operation.

In order to condition the animal realistically to his surroundings, McDonnell Aircraft Corporation fabricated six training couches identical to the flight couch with the exception that they were to be used at ambient atmospheric pressure and that the psychomotor apparatus would be programed with standard laboratory equipment. In addition, the McDonnell Aircraft Corporation furnished four plywood mockups of the Mercury spacecraft in order to simulate the physical surroundings of the couch. The mockups included replicas of the astronaut panel and panel lights.

At the same time that training was progressing, the Veterinary Services Branch of the Aeromedical Research Laboratory began collecting normal baseline data on the entire colony of immature chimpanzees. These data consisted of complete physical examinations, including X-rays at specified intervals; and in addition, examinations were made immediately before and after any work session or aircraft flight of the animal. Data were gathered on normal blood and urine values; X-rays were taken; and blood pressure, respiration, and heart rate were measured at regular intervals. At this time, because postlanding temperatures were in the critical zone, the Ecology Section of the Bio-Astronautics Branch began thermal-humidity experiments to determine the temperature and humidity tolerance of the chimpanzees. Details of the method of restraint were worked out by the Aeromedical Research Laboratory and the restraint suits were designed and fabricated by the Aerospace Medical Laboratory, Aeronautical Systems Division, Dayton, Ohio. A series of simulated flights were then conducted on the centrifuge at the Aerospace Medical Laboratory to determine the effects of accel-

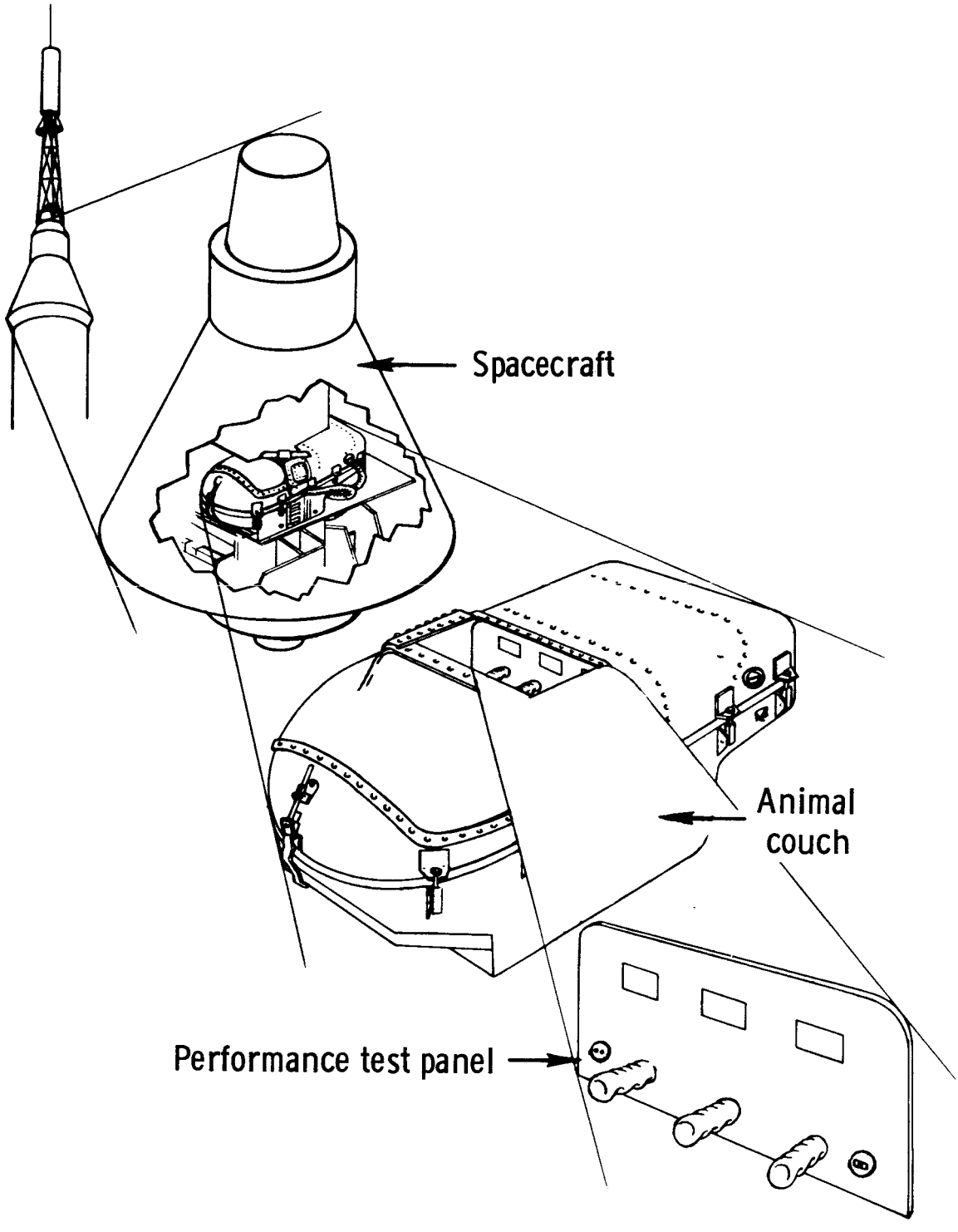



FIGURE 2–1.—Diagram of the location of the animal pressurized couch within the Mercury spacecraft and the placement of the performance test panel within the couch. Immediately to the right of the three levers are the spring loaded fingers that present the special banana-flavored reward pellets. In the rectangles above the levers, the colored lights and symbols are displayed. The water dispenser is not depicted but lies to the right of the animal's head in the top portion of the couch.

eration and vibration on the chimpanzee, to acclimate the animals to the flight conditions, and also to evaluate the complete chimpanzee-couch system.

The medical recovery plans were formulated by Manned Spacecraft Center, the Office of the Staff Surgeon, Patrick Air Force Base, and the Aeromedical Research Laboratory. Veterinary officers and veterinary technicians of the U.S. Army and the U.S. Air Force were selected and sent in small groups to the Aeromedical Research Laboratory for 2 weeks training in the care and handling of chimpanzees. A total of 35 veterinary technicians and 10 veterinary officers were so trained.

The prelaunch operation began on January 2, 1961, when 20 officers and airmen of the Aeromedical Research Laboratory flew from Holloman Air Force Base to Cape Canaveral with 6 chimpanzees and the necessary support equipment. The animals were moved immediately upon arrival into an aeromedical van complex which had in the meantime been prepared for them and placed within the fence of Hangar S on the Atlantic Missile Range.

## Reference

1. Green, Cloid D., Welch, B. E., et al.: Studies of Escape from Ballistic Space Vehicles—I. Biomedical Evaluation. School of Aviation Medicine, Brooks Air Force Base Rep. 61-29, Apr. 1961.

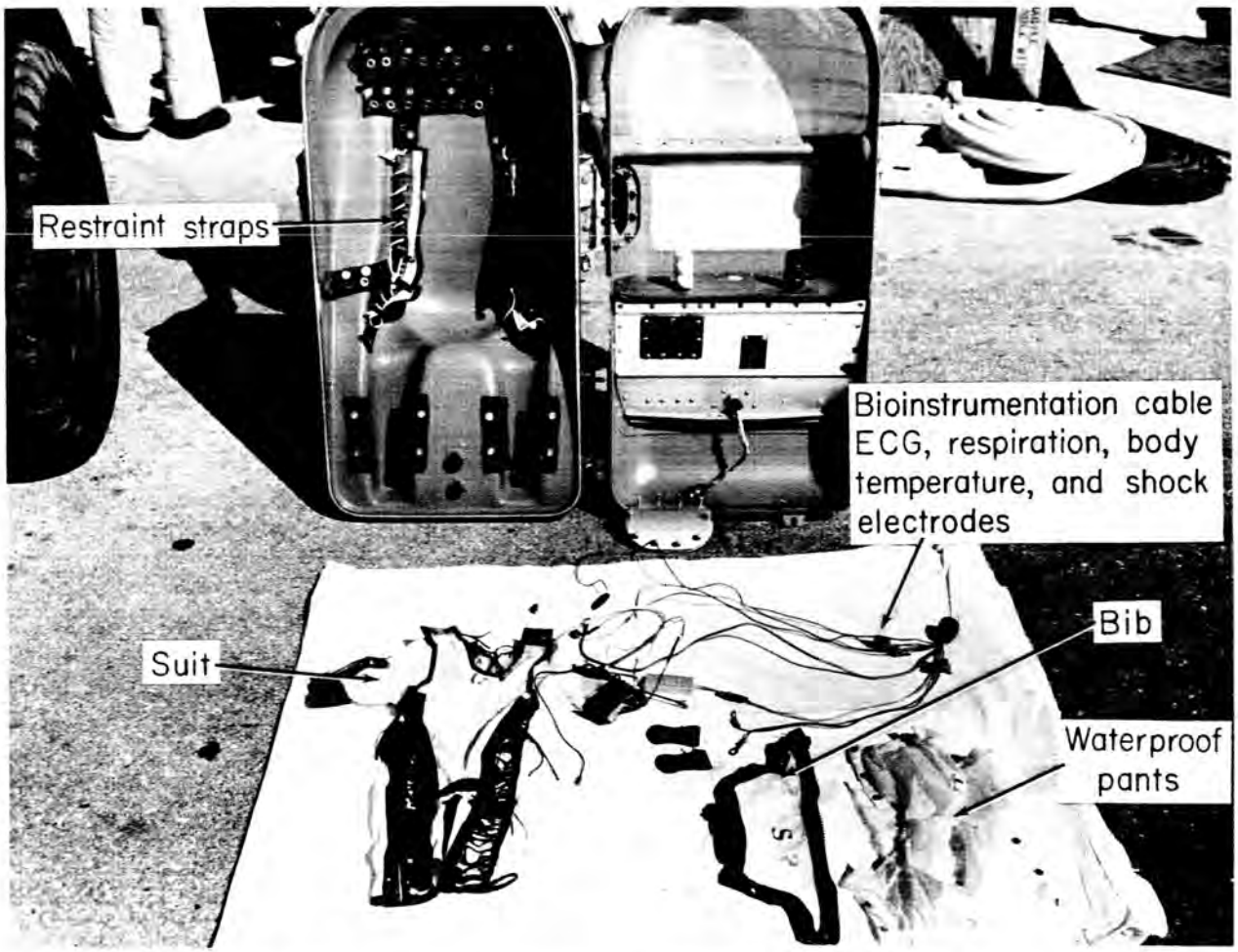



FIGURE 2-2.—Display of the ballistic flight couch showing on the left of the picture the couch proper with the tabs and adjustments for attaching the subject's restraint suit. The suit is shown immediately below the couch. The nylon lacing adjustment can be seen. On the right is the couch lid containing the ballistic psychomotor apparatus and two levers. The hand access cover can be seen at the base of the lid. It fits over a hole seen above and to the left of the white lever. On the right and below are the diaper and nylon waist panel used for separating the animal from his rectal probe. Above on the sheet are the two psychomotor stimulus plates contoured to fit the soles of the feet; the respiratory sensor, rectal probe, and the ECG sensors all connected to a plug which in turn fits into a receptacle on the base of the couch on the left of the photograph.

# 3. MR–2 OPERATIONS

By Norman E. Stingely,*
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## Prelaunch Activities

The animal operations at Cape Canaveral, Florida, for the MR–2 flight began January 2, 1961, with the arrival of 6 chimpanzee subjects and 20 scientific and technical personnel. The early arrival, 29 days prior to the launch date, was required to stabilize the animal subjects, to enable the preparation team to practice with the animal and its flight apparatus, and to perform spacecraft systems checkouts with chimpanzee subjects. A minimum of 21 days for subject acclimatization was deemed necessary to give the chimpanzees time to adapt to the change in environment. (The altitude at Holloman Air Force Base, N. Mex., is approximately 4,000 feet above sea level as opposed to the sea-level altitude at Cape Canaveral, Fla.)

The facilities for quartering, training, and preparing the subjects for flight consisted of seven trailers (two caging, two training, one medical, one transfer, and a house trailer) located in a fenced enclosure adjacent to Hangar S at Cape Canaveral, Florida. (See fig. 3–1.) The basic requirements and the designs of the interior for these vans were formulated by the Manned Spacecraft Center with the cooperation of the Aeromedical Research Laboratory. The vans were designed, engineered, and supplied by NASA Manned Spacecraft Center (ref. 1). One caging and one training van were connected front to front in train couple fashion which provided two identical caging-training units. In order to avoid a possible spread of disease, the chimpanzees were separated, three animals to each caging-training unit, with separate provision for food storage and food preparation.

Each training van had two training cubicles and one Mercury spacecraft mockup to simulate isolation conditions of the Mercury flight while the chimpanzee subjects maintained their proficiency on the psychomotor performance tasks. (See section 4.) During the preflight period 29 training sessions were conducted.

The medical van was equipped as a combined clinical and surgical facility for physical examination, clinical laboratory analysis, minor surgery, and treatment of illness or injury. It was also used for the installation of the various biosensors, the restraint garment, and placement of the animal in the couch.

The transfer van was designed to accommodate either a man or a chimpanzee subject in the couch while enroute from the Hangar S complex to the launch pad. In addition, it was used for checkout of the physiological sensors and psychomotor apparatus and for testing the pressurized couch to determine if it was in a flight-ready condition. An eight-channel Sanborn 350 recorder was used for the physiological and psychological performance checks and to record preliminary flight data. A Firewell pressure-suit test console with air supply was used for the pressure check of the chimpanzee couch and to sustain the subject while in the transfer van. A portable liquid-oxygen supply was used for sustaining the subject while moving from the transfer van up to the gantry and into the spacecraft.

The animal complex was manned at all times to maintain continuous observation of the animal colony, to detect any illness, and to preclude any emergency condition, such as faulty temperature regulation in the caging vans. The house trailer served to house personnel on duty at night and was used as an office for the operation.

Five practice countdowns were conducted by the medical preparation team for the MR–2 flight. They consisted of preparing the subject and couch, and proceeding up the gantry. The couch was placed outside or inserted into the spacecraft and connected to the spacecraft environmental control system (ECS) and electrical system. One countdown was performed for a telemetry check, one for a spacecraft-pressure check,

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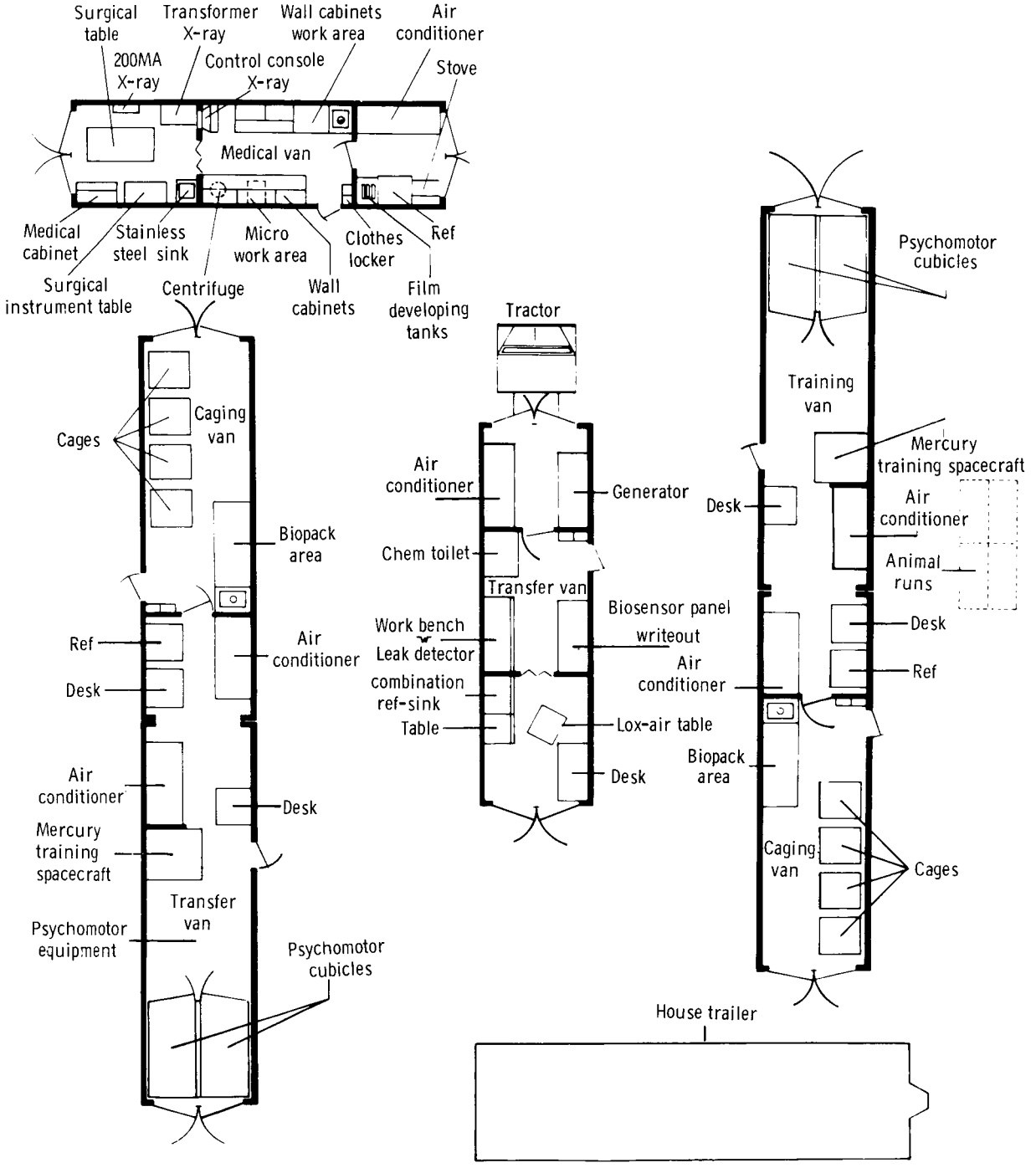



FIGURE 3-1.—Animal van complex for the MR-2 and MA-5 flights. Each van measured 28 by 8 feet.

one for a radio-frequency compatibility test, and two were simulated flights.

## Flight Preparation and Insertion

The flight preparation and insertion of the couch into the spacecraft was performed in a two-part countdown. The time-consuming operations, such as the physical examination of all potential flight subjects and a complete checkout of all animal preparation equipment were performed on T—1 day; the actual animal preparation took place on T day. The sequence of events as they occurred, with times expressed as Eastern Standard, are presented in the following paragraphs.

### T—1 Day (January 30, 1961)

The activities of the day prior to the flight were as follows:

*Ground support equipment.*—The following checks of ground support equipment were made at 8:00 a.m. (T—26 hr 54 min):

1. All vans were checked to see if the necessary equipment and supplies were available and in their proper place.
2. A check of all test equipment was initiated.
3. The pressure-suit console and air supply were checked for proper operation.

*Flight equipment.*—At 8:00 a.m. (T—26 hr 54 min) the three available flight couches and sensor cables were checked to see that the ECG leads, respiration sensors, rectal temperature thermistors, and psychomotor programers functioned within specifications.

At 2:00 p.m. (T—20 hr 54 min), restraint suits and couch attachments were selected and fitted to the flight and backup subjects. They were then placed in their respective flight couches and fitted to them.

*Diet and feeding schedule (all animals).*—All subjects were placed on a diet and feeding schedule at T—26 hr 54 min. At that time, each subject received 15 commercial food pellets and one-fourth of an orange. All subjects received 12 ounces of a low bulk diet at 2:00 p.m. (T—20 hr 54 min) and again at 8:00 p.m. (T—14 hr 54 min).

*Clinical studies.*—The following clinical studies were conducted at 8:00 a.m. (T—26 hr 54 min):

1. Blood and urine samples for analysis and Metabolic Profile Studies were collected and processed.
2. A comprehensive clinical ECG and overall body X-rays were conducted.

*Water intake.*—Water intake was limited to a total of 800 cc from T—24 hours through recovery.

*Physical examination.*—A complete physical examination was given to each of the four primary subjects at 8:00 a.m. (T—26 hr 54 min). The physical examination included a check of body weight, rectal temperature, blood pressure, pulse, respiration, skin, eyes, ears, nose, mouth and throat, chest, abdomen, and extremities.

At the completion of the physical examination, the flight and backup animals were chosen. This decision was based on the veterinarian's judgment, the physical condition of the animals, and the psychologist's evaluation of the animal's psychomotor performance ability.

### T Day (January 31, 1961)

The chronological events of the launch day are as follows:

*1:15 a.m. (T—9 hr 36 min).*—A physical examination of the flight subjects was again conducted, and physiological sensors, disposable diapers, and plastic waterproof pants were placed on the subject.

*1:45 a.m. (T—9 hr 6 min).*—An operational test of the attached sensors was made in the medical van. The electrical resistance of the ECG leads was checked to insure compatability with the spacecraft ECG amplifiers. A telethermometer was used to test the operation of the rectal temperature thermistor.

*2:03 a.m. (T—8 hr 51 min).*—The subject was placed in the prefitted suit and zipped and laced in the couch (figs. 2–2 and 3–2). The restraint suit consisted of nylon webbing reinforced by nylon tape at the cuffs and other points of stress. The suit which was developed by the Aeromedical Research Laboratory personnel and fabricated by the Aeronautical Systems Division represented a modification of suits previously used in chimpanzee research. (See ref. 2.) Provisions were made for expansion of the suit to compensate for growth of the subject by zipping the suit to preattached leg and torso tabs. Loose restraint of the legs with nylon cord completed the couch restraint. Psychomotor stimulus plates were attached to the sole of each foot and were electrically checked for continuity. The panel, designed to prevent the subject from reaching the sensor leads, was plugged into the couch base.

*2:31 a.m. (T—8 hr 20 min).*—The flight subjects and couch base were moved to the transfer van. Immediately thereafter, the backup subject was moved to the medical van and prepared to the same point as the flight subject. The flight subject and complete couch were weighed and ballasted to a prearranged total of 95.45 pounds. The instrumentation within the couch was then attached to the Sanborn recording equipment and a check made for normal ECG and respiration waveforms and for rectal temperature. Respiration



FIGURE 3-2.—Animal in couch (compare with fig. 2-2). The lacing on the arms to fit the adjustable nylon restraint suit is visible. The waist panel with its zipper which is attached to the couch lid can also be seen.

rate, heart rate, and rectal temperature were recorded every 5 minutes, both to monitor the subject and to plot trend data to aid the flight control surgeons in determining the subject's flight readiness.

The digital counters on the psychomotor programer were read and recorded, and the couch lid was electrically connected to the couch base and loosely placed upon it without tightening the pressure seat. Power was applied to the psychomotor programer, and the programer was checked to ascertain that the right- and left-hand levers produced a signal each time they were depressed and that a pulse appeared with every presentation of shock and blue light.

*3:02 a.m. (T—7 hr 52 min).*—The flight and backup subjects received 8 ounces of the prescribed diet. The lid tiedown bolts were all torqued to 15 inch-pounds. The inlet and outlet air hoses were attached to the couch and a flow of air was initiated. The couch porthole covers were attached and torqued to 10 inch-pounds. Leakage was checked by pressurizing the couch to 5 psi and recording any pressure drop. The leak rate was below 50 cc per minute, the lowest that could be read on the pressure-suit test console. Fifteen minutes of psychomotor performance data were collected during this procedure. The couch pressure was then returned to ambient and the subject was ventilated with an air flow of 75 to 100 liters per minute until he was moved up the gantry. The subject remained on standby in the transfer van at the animal complex until directed by the blockhouse surgeon to move to the launch pad.

*5:04 a.m. (T—5 hr 50 min).*—The transfer van was directed to move to the launch pad and arrived at 5:29 a.m.

*6:05 a.m. (T—4 hr 49 min).*—The subject and couch were switched from the transfer van air supply to the portable liquid-oxygen supply, moved up the gantry, inserted into the spacecraft, and connected to the ECS and electrical system. The physiological monitoring of the flight subject was then switched to the blockhouse.

Immediately after the departure of the flight subject, the backup subject was placed in the transfer van. The subject and couch were checked by the same procedure as that for the primary subject and placed on standby.

*ECS monitoring.*—The ECS was monitored by a direct line to the blockhouse while a final bubble-leak check was performed in the spacecraft at the junction of the inlet and outlet ECS hoses. Three recordings were made of the psychomotor responses at the blockhouse before the spacecraft hatch closure was completed. The durations of these checks were 1 minute 57 seconds, 3 minutes 40 seconds, and 1 minute.

Before the gantry was removed, the transfer van was moved to an adjacent blockhouse. Monitoring of the backup subject in the transfer van continued until T—30 minutes when all personnel and the backup subject and couch with portable air supply were moved into this blockhouse.

Hatch closure was completed at 7:10 a.m. and the gantry was removed at 8:05 a.m. At 9:08 a.m. the count was recycled, the gantry returned, and the hatch opened to cool an inverter.

The count was resumed at T—2 hr (10:15 a.m.) and performed at an accelerated pace. Portions of the count were not repeated. Again three psychomotor recordings were made in the recycled count. The duration of these checks were of 2 minutes 4 seconds, 1 minute 38 seconds, and 1 minute 50 seconds. The

last check began just prior to lift-off and continued in flight.

*Lift-off.*—Lift-off occurred at 11:54:51 a.m.

## Flight Characteristics

The spacecraft reached an apogee of 136.2 nautical miles and a range of 363 nautical miles in a flight lasting approximately 16 minutes 29 seconds.

Upon separation from the launch vehicle, the spacecraft rotated slowly about all three axes. The motion in pitch and yaw became attitude stabilized at 3:54 minutes with a steady roll rate of 9.5° per second which continued until main parachute deployment. At T+8 minutes 55 seconds, the spacecraft began to turn around and to reenter the atmosphere with the heat shield pointed in the direction of flight.

The longitudinal acceleration loads imparted to the subject in the transverse plane are presented in figure 3–3. The acceleration increased from 1.2g at lift-off to 6.5g at T+2 minutes 17 seconds. At T+2 minutes 18 seconds the escape rocket fired, due to a failure in precise timing of launch-vehicle cutoff, and the acceleration peaked at 17.0g. It then returned to 0g for a 6½-minute period. Reentry deceleration started at T+9 minutes 20 seconds, reached a maximum of 14.6g at 9 minutes 36 seconds, and then decayed to 1.3g. The drogue-parachute deployment caused a pulse of less than 0.5g at T+10 minutes 54 seconds, and the main-parachute deployment caused a brief 3g deceleration at T+11 minutes 28 seconds. Lateral and head-to-foot accelerations during flight were negligible. Abrupt landing decelerations in the longitudinal plane of the spacecraft ranged from the tolerable values of 20g to −7g, the lateral deceleration varied from 3.5g to −4.7g, and the head-to-foot deceleration with respect to the subject ranged between 3.4g to −16.8g.

The ECS was designed so that the subject breathed 100-percent oxygen from lift-off until descent when the snorkel valve opened at 18,000 feet. As the craft went to altitude, the pressure reduced to and leveled off at 5.5 psi and then on descent, just prior to landing, returned to ambient pressure.

The couch inlet temperature did not change significantly during the flight. It was 58° F at lift-off and varied ±0.5° F until the craft reached an altitude of 18,000 feet on descent when the ECS opened to ambient air. The couch temperature at landing was 66° F.

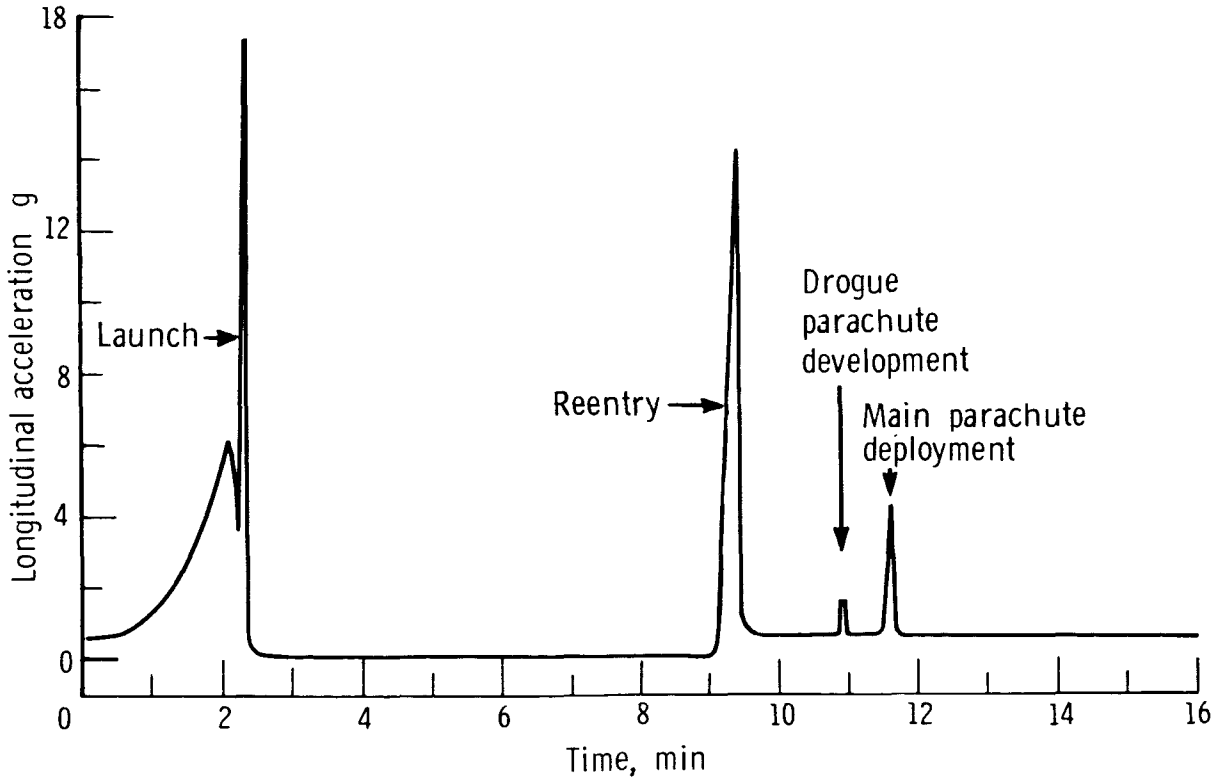



FIGURE 3–3.—The longitudinal acceleration profile of the Mercury-Redstone 2 flight. The extra peak to 17g during launch was caused by escape rocket firing.

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## Monitoring

Real-time monitoring of the subject occurred at three Cape Canaveral locations. It began in the transfer van and was then transferred to the blockhouse after the subject was placed in the spacecraft. The blockhouse was monitored by hardline transmission (spacecraft umbilical) until T—30 minutes when telemetry commenced; then both blockhouse and Mercury Control Center (MCC) monitored until lift-off. After lift-off MCC was the sole monitor. The three monitoring stations were connected by Missile Operations Intercom System (MOPS), a closed-loop voice link. In addition, the Hangar S medical facility, the point recovery team, emergency spacecraft recovery team, Patrick Air Force Base hospital, and Grand Bahama medical facility were informed of countdown events via MOPS.

The blockhouse monitoring phase used two consoles which displayed physiological, psychological, and environmental control system variables. In addition, two channels of ECG (leads 1 and 3), respiration waveform, rectal temperature, and three psychomotor variables were recorded on a strip chart. Range time was substituted as a readout in lieu of the fourth psychomotor channel. Indication of mild shock to the subject during the blockhouse period was obtained through a disturbance of the ECG waveform. The console also provided for the display of either lead of ECG on an oscilloscope. Adjacent to the physiological and psychological display was the environmental control system monitoring console. The environmental data which had direct bearing on the condition of the subject included couch and spacecraft pressure and temperature, amount of oxygen in the ECS, and available coolant.

At the Mercury Control Center, the data readout was the same as that at the blockhouse except that the transmission of an electrical shock was recorded.

Since this was a suborbital flight, the range stations of the Worldwide Mercury Network did not participate. Two Atlantic Missile Range stations (San Salvador and Grand Turk) participated for purposes of checking telemetry signal quality.

In addition to monitoring records, both the Cape Canaveral Telemeter II and an airborne station collected data. Other data sources for determining the status of the subject during flight were an onboard tape recording and photography of the subject.

## Recovery and Postflight Periods

Three major animal recovery areas were used. They were the emergency spacecraft recovery area, the point recovery area, and the downrange normal recovery area. All of these areas permitted the exercise of the manned procedures. Emergency spacecraft recovery effort was designed to provide care for the subject in the event of a canceled mission (abort of the mission prior to launch). The point recovery effort, a highly coordinated land, sea, and air effort, was designed to provide the retrieval of the occupant in the event of a pad or launch abort; it extended for a 12-mile radius from the launch site. The normal recovery effort consisted of an airborne surveillance supported by eight ships distributed along the line of probable landing. A land-based medical facility on the Grand Bahama Island for postflight examination and animal care was provided. The movement of the animal after recovery was to this land-based facility.

The significant events occurring during recovery included the retrieval of the Mercury spacecraft by helicopter and its delivery to the recovery vessel at 3:40 p.m. e.s.t., January 31, 1961. The spacecraft hatch was opened at 3:42 p.m. e.s.t.

Moisture on the interior of the plexiglass couch cover prevented observation of the chimpanzee; however, it was heard vocalizing normally. The environmental control system (ECS) inlet hose was disconnected at 3:44 p.m. e.s.t. and fresh air (ship's air) under pressure was introduced into the couch. The right-hand couch cover porthole was removed and the air source was then placed in the port. The fresh air cleared away the condensate on the interior of the couch cover and the animal's condition appeared to be normal. Upon removal of the couch from the spacecraft, the cover was removed and the subject and lower half of the couch were transported to the ship's sick bay where the chimpanzee was given a physical examination.

He was retained overnight on the recovery ship until the morning of February 1, 1961. The subject and equipment were then transported by helicopter to the Grand Bahama forward medical facility and arrived at 8:10 a.m. e.s.t.

The subject, equipment, and personnel were then transferred by pressurized aircraft to Patrick Air Force Base, Florida, and returned to the Cape Canaveral animal complex. There, another physical examination was performed. A post-test calibration check was made of the psychomotor equipment and physiological sensor harness. The test indicated that all equipment was operating within preflight specifications. On February 2, 1961, two ½-hour psychomotor performance sessions were conducted and the physiological variables were recorded. Finally, on February

3, 1961, a similar test was conducted, and on the next day the subject was returned to Holloman Air Force Base, New Mexico.

## References


1. Stingely, Norman E.: Countdown and Procedures for Project Mercury Flight MR–2 (Chimpanzee Subject). Air Force Missile Development Center TR–61–20, June 1961.
2. Archibald, Erwin R., and Ward, William E.: Chimpanzee Temperature-Humidity Tolerance Tests—Control Tests at 80° F, 50 Percent Relative Humidity. Air Force Missile Development Center TR–61–11, Apr. 1961.

# 4. BEHAVIORAL APPARATUS *for the* MR–2 AND MA–5 FLIGHTS

By E. J. Brown* and R. D. Iwan*

As the preceding sections have indicated, the Mercury animal program generated a requirement for the development of lightweight, miniature, highly reliable equipment with which a series of tasks could be presented to the animal. This "psychomotor apparatus" had to fit into the confines of the animal's pressurized couch and its development within the imposed limits of time, space, and weight presented considerable difficulties. This section describes the solution of the McDonnell Aircraft Corporation to the problem of producing an instrumentation package which met the specifications given by the NASA and the 6571st Aeromedical Research Laboratory.

## Apparatus

Two versions of the apparatus were developed; one for use in the ballistic flight (fig. 4–1) and the other

*McDonnell Aircraft Corp.

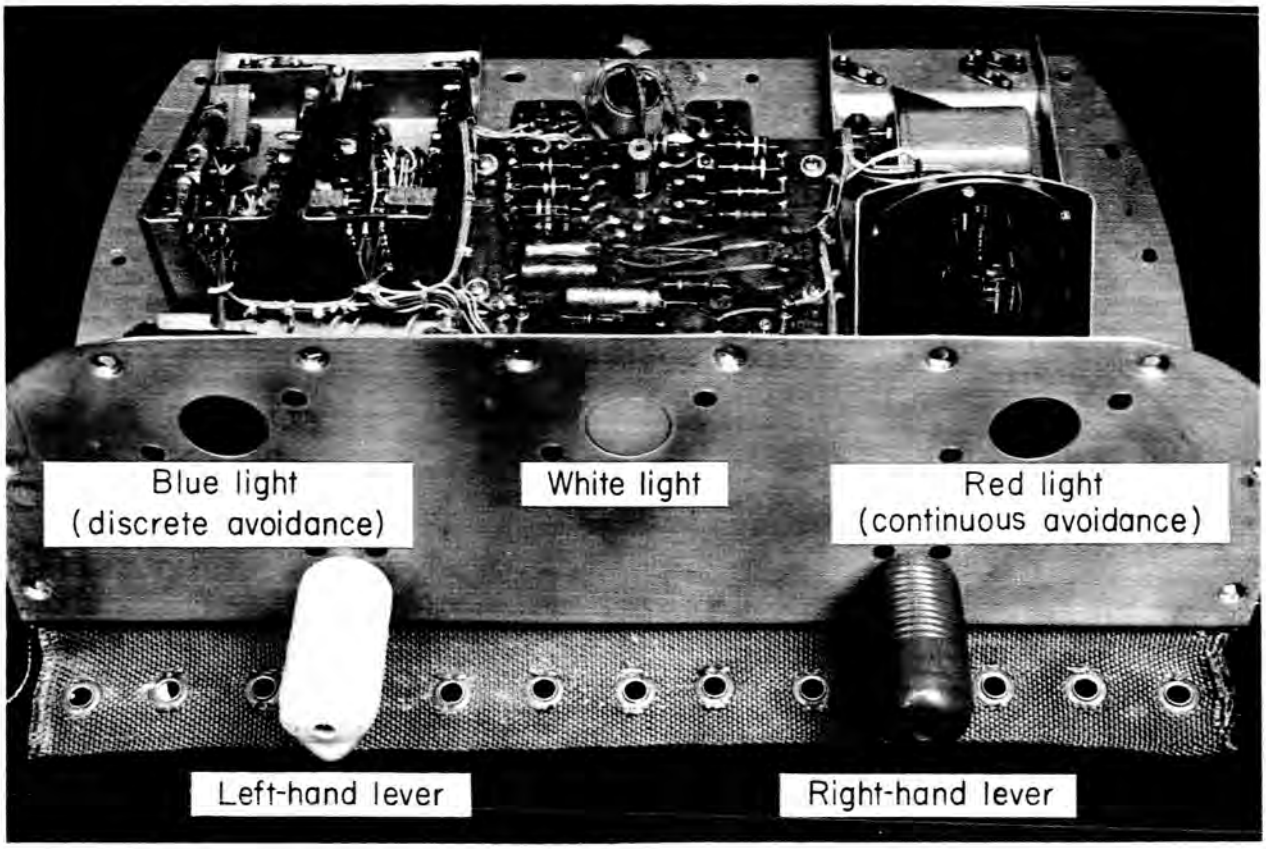



FIGURE 4–1.—The MR–2 ballistic flight psychomotor panel with its attached CA–DA programer. (Also see fig. 5–1.) The white light indicates that the right lever has been satisfactorily depressed. The blue light must be extinguished by pressing the lever within 5 seconds or a shock will be received.

for use in orbital flight (fig. 4–2). The ballistic unit presented two shock-avoidance programs. The primate had to depress levers in response to colored light stimuli within a certain time period to avoid a mild shock. The orbital unit had three additional programs during various phases of which the primate obtained drink and banana-flavored food-pellet rewards or shock punishment for error or failure to respond. The stimuli for a particular program consisted of colored lights and symbols presented in display units. The performance tasks are described in sections 5 and 9.

## System Operation

The system is composed of two types of basic parts, a stepper switch and a timer.

Of the stepper switches, one utilizes 9 positions on 7 wafers and the other 20 positions on 9 wafers. Since space was at a premium, commercial switches were modified; and a container was designed to eliminate as much waste space as possible and yet to provide a hermetic seal on the coil and contacts.

The time circuit is a radical departure from conventional types. One of small size, low power drain, high reliability, large dynamic range, and low weight was required. Extreme variations in the supply voltage and excessive transients further complicated the problem.

Figure 4–3 is a schematic diagram of the basic timing circuit which is used to give time periods from 0.125 second to 900 seconds. Basically, it is constant-current generator formed by resistors $R_1$, $R_2$, transistor $Q_1$, and a Zener diode $D_6$ feeding capacitor $C_1$. This timing circuit causes the voltage across $C_1$ to rise linearly until $Q_2$, a unijunction transistor, fires and discharges $C_1$ to the valley voltage of the unijunction. Neglecting leakage currents, the time period $T=\frac{KC}{I}$ where I is constant current, C is capacitance, and K is a proportionality constant. As the circuit is shown, it is highly susceptible to voltage variations and negative-going transients on the power supply bus. Figure 4–4 shows the major modifications incorporated in this circuit to eliminate power prob-

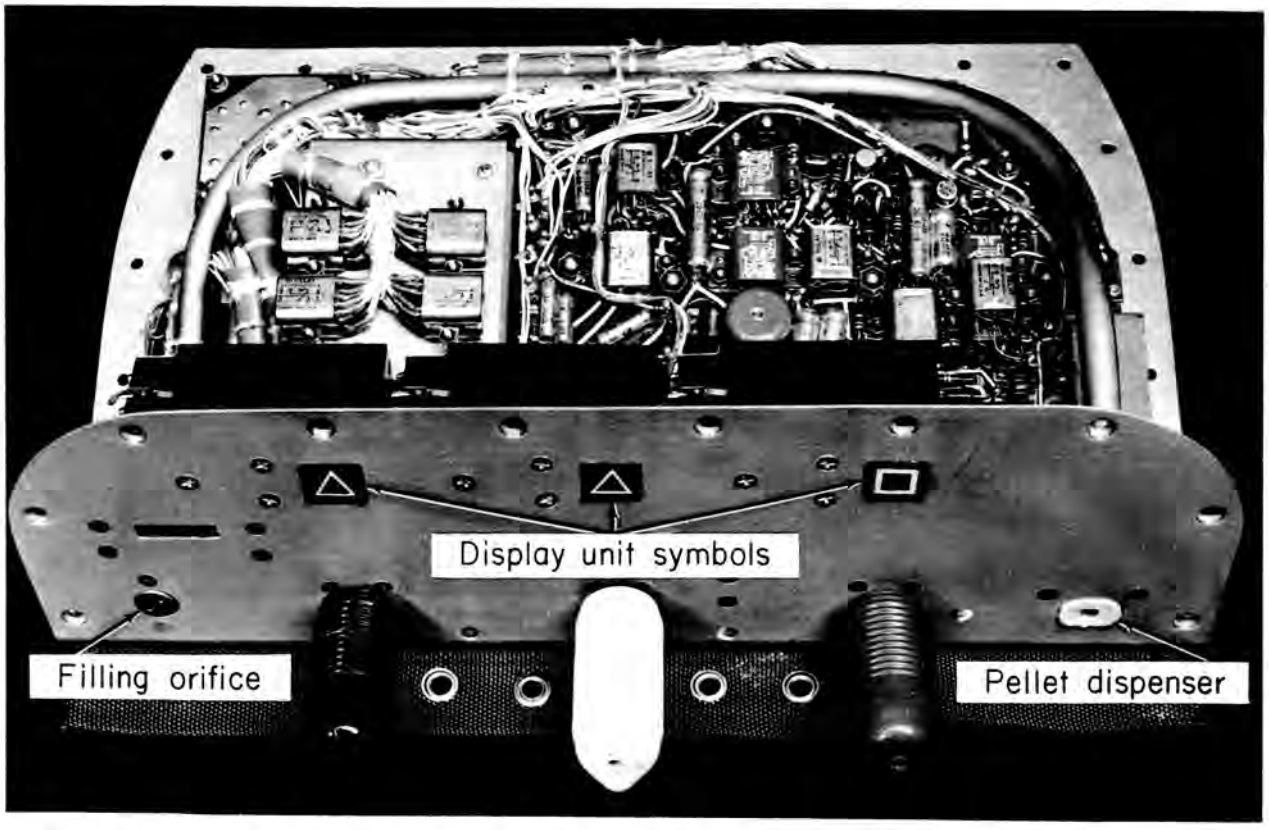



FIGURE 4–2.—Advanced orbital MA–5 psychomotor flight programer with the accompanying panel (compare with figs. 2–1 and 9–1). A digital counter records lever presses. Illustrative model symbols are pasted to the display unit windows above each lever. The reservoir tube of the pellet dispenser curves back around the programer to the circular filling orifice. The waist restraint panel is laced to the tab appearing below the panel.

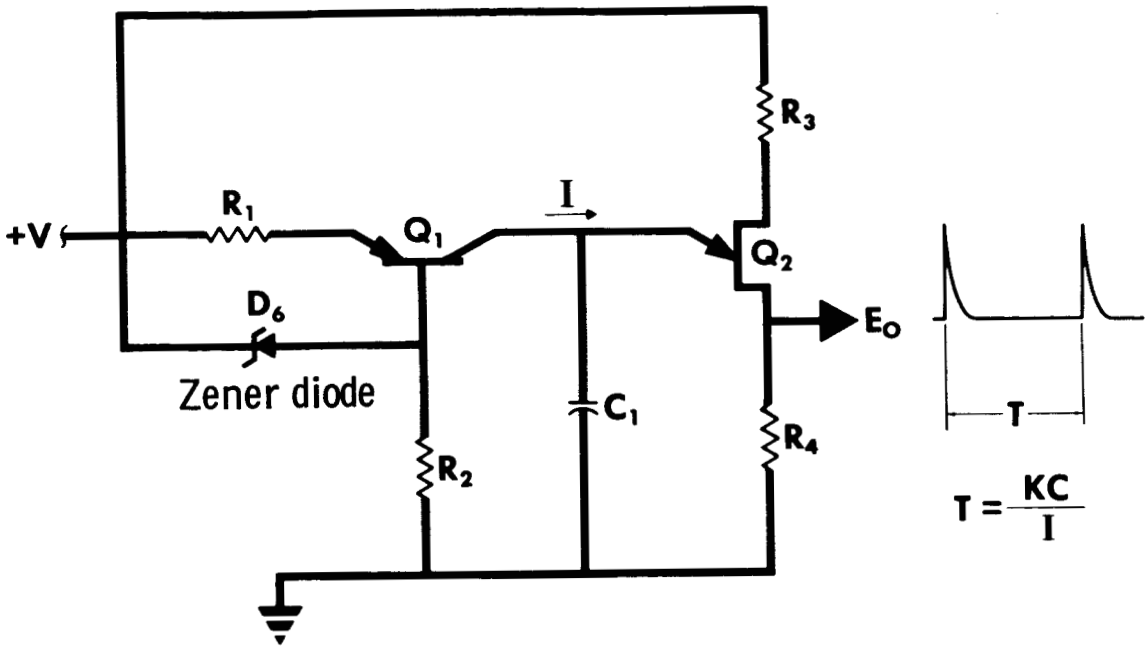



FIGURE 4-3.—Basic timing schematic diagram.

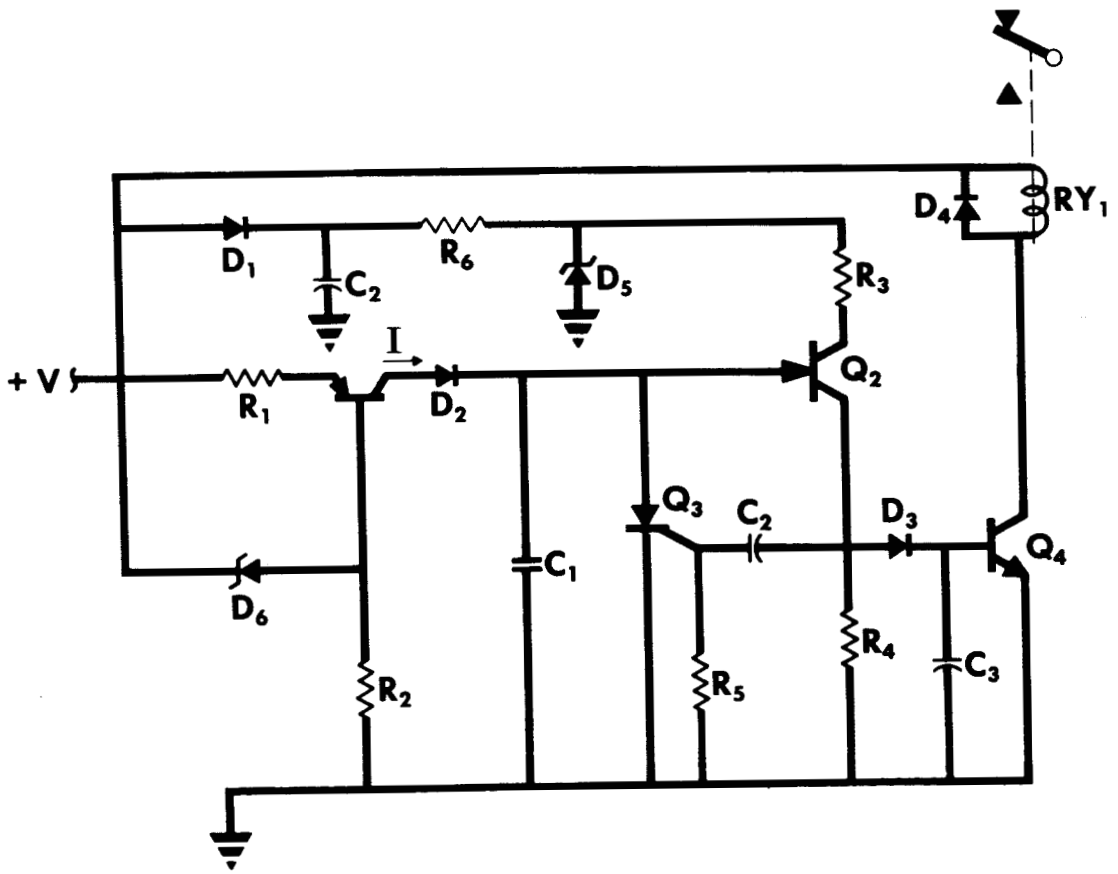



FIGURE 4-4.—Timing circuit with switching and transient protection.

lems and to improve the overall characteristics. A regulated voltage to Base 2 of the unijunction transistor is provided by $D_1$, $D_5$, $R_6$, and $C_2$, to prevent input voltage variations from varying the firing voltage. The diode $D_2$ prevents $C_1$ from discharging through a transistor during a severe negative-going transient. The capacitor $C_1$ is discharged by $Q_3$, $R_5$, and $C_2$ to approximately 1 volt above ground, which is lower than the valley voltage of $Q_2$. It is also possible to reset $C_1$ to zero with an inhibit pulse prior to the firing of $Q_2$ by coupling a trigger signal to the gate of $Q_3$.

The diode $D_3$ enables $C_3$ to obtain a charge when $Q_2$ fires and yet to hold or stretch the pulse so that $Q_4$ will reliably pull in $RY_1$.

The diode $D_4$ is used to suppress the transient produced by the interruption of current through the inductance of $RY_1$ when $Q_4$ stops conduction.

By varying the value of $R_1$, the period of the timer can be varied greatly. For excessive changes in the period, $C_1$ must be charted too. For periods up to 2 minutes, 50 microfarads were used for $C_1$; for 2 to 6 minutes, 300 microfarads were used; and for 5 to 15 minutes, 800 microfarads were used.

Figure 4-5 aids in explaining the operation of the system. When power is applied, the master timer begins a countdown and the program selector channels provide power through the display selector to turn on the red light in the right-hand display unit and route power to start the discrete avoidance and continuous avoidance programs. While in this mode of operation, right-hand lever depressions inhibit a shock for 15 seconds; meanwhile, the blue light comes on every 2 minutes and requires a depression of the left-hand lever within 5 seconds or the light is terminated and a shock is delivered.

After 15 minutes the master timer delivers an output to the program selector which turns the power off for all but the cumulative response circuits and allows a 6-minute time-out or rest period.

At the end of 6 minutes, the master timer delivers another output to the program selector, which, in turn, powers the circuits required for the differential reinforcement of low rates (DRL) program. A green light in the right-hand display window alerts the primate to the program identity. A 20-second timer begins to count down and permits the "drink" dispenser to be armed at the end of 20 seconds if the right-hand lever is depressed. If it is depressed prior to the passage of 20 seconds, the timer is reset; and the "drink" dispenser cannot be armed for an additional 20 seconds. Once armed, it will remain so for 5 seconds or until the primate has received his allotted amount of liquid, whichever comes first. This program lasts for 10 minutes, at which time the master timer advances the program selector to the second timeout period.

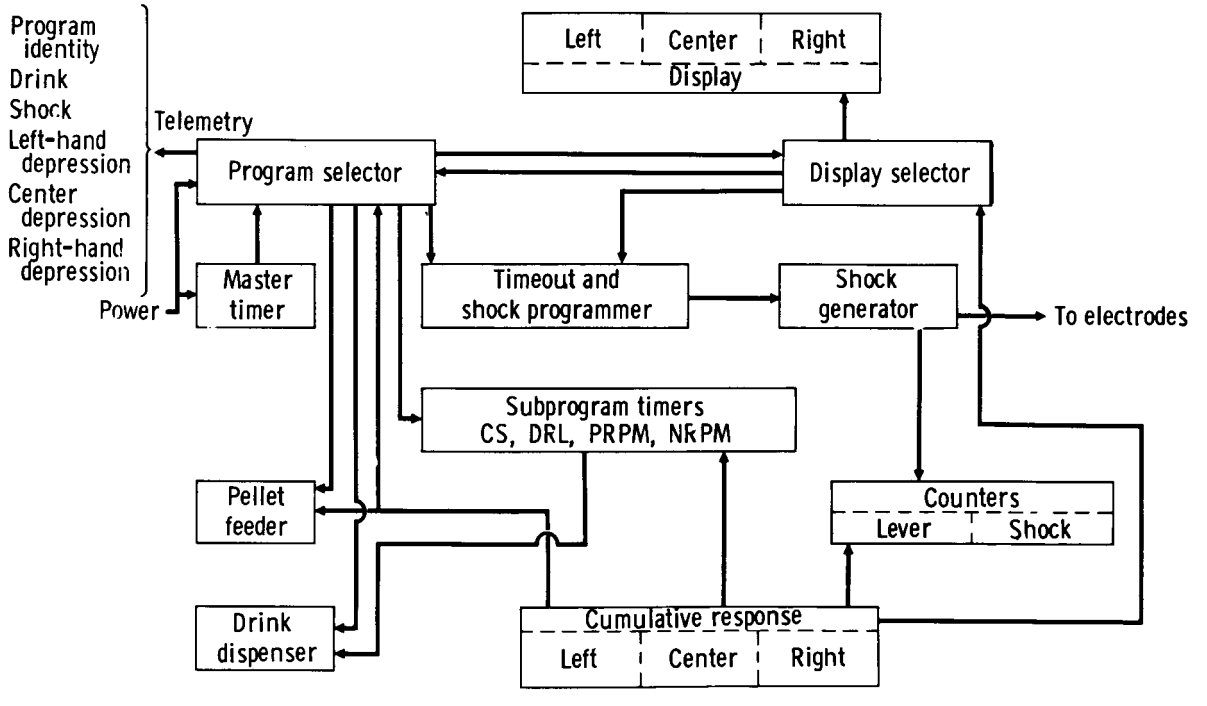



FIGURE 4-5.—Orbital psychomotor block diagram.

After 6 minutes the master timer advances the program selector to fixed ratio (FR) reinforcement program for food rewards. The stimulus for this program is the illumination of a yellow light on the center display window. When this light is on, the subject has to press the center lever 50 times for one pellet of food. After 10 minutes the animal has another rest period.

At the end of 6 minutes the master timer advances the program selector to the positive reinforcement perceptual monitoring (PRPM) or negative reinforcement perceptual monitoring (NRPM) oddity problem mode. The choice of modes is determined prior to launch. A latching relay is preset electrically to program the desired mode of operation. In the PRPM mode, symbols are displayed in each of the three display windows. Displays in two of the windows are always alike, and one is always different. If the primate depresses the lever under the odd symbol, he is rewarded with a banana pellet and a new display. If a wrong lever is depressed, the primate is punished by not receiving a pellet and a 15-second blackout of the displays. After 15 seconds, the same display is shown again.

The oddity problems last until 36 combinations of displays have been shown or until 5 minutes have elapsed, at which time the master timer will return the program selector to the discrete-avoidance-continuous-avoidance mode and the entire program is repeated.

The oddity problem which was employed in the MA–5 flight uses negative reinforcement (NRPN) in order to conserve food pellets. A wrong answer results in a ½-second shock, followed by a 15-second blackout of the displays and a representation of the same set of symbols. A right answer results in no shock, a 15-second timeout, and a new set of symbols. If no response is given in 35 seconds, a shock is delivered every 5 seconds until either a right or a wrong answer is given. This program lasts until 18 combinations have been shown twice or until 10 minutes have elapsed.

The following information was telemetered over four channels:

For the discrete-avoidance-continuous-avoidance task,

(1) Shock indication
(2) Number of left-hand-lever switch closures
(3) Blue light "on" time
(4) Number of right-hand-lever switch closures

For timeout,

(1) Program identification
(2) Number of left-hand-lever switch closures
(3) Number of center-lever switch closures
(4) Number of right-hand-lever switch closures

For the differential reinforcement of low rates task,

(1) Program identification
(2) Number of left-hand-lever and number of center-lever switch closures
(3) Drink indication
(4) Number of right-hand-lever switch closures

For the fixed-ratio (food reward) task,

(1) Program identification
(2) Number of left-hand-lever switch closures
(3) Number of center-lever switch closures
(4) Number of right-hand-lever switch closures

For the oddity problem,

(1) Program and display number indication
(2) Number of left-hand-lever switch closures
(3) Number of center-lever switch closures
(4) Number of right-hand-lever switch closures

In addition to the telemetered data, an electromechanical counter on the front panel records the total cumulative number of lever switch closures. (See fig. 4–2.)

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# 5. PERFORMANCE ASPECTS *of the* MR–2 FLIGHT

By Frederick H. Rohles, Jr.,*
Marvin E. Grunzke,** and
Richard E. Belleville, Ph. D.***

In April of 1959 when the National Aeronautics and Space Administration defined the animal program of Project Mercury, it was specified that both behavioral and physiological measurements would be made on the subject. The behavioral aspects of this program were assigned to the Comparative Psychology Branch of the Aeromedical Research Laboratory, Holloman Air Force Base, N. Mex. (ref. 1). The purpose of this section is to describe the performance aspect of the first of the chimpanzee flights of Project Mercury, which was the ballistic flight of the Mercury-Redstone 2 spacecraft on January 31, 1961.

## Methods

### Subject

The subject, Ham (Aeromedical Research Laboratory subject No. 65), was a male chimpanzee weighing 37 pounds. On the basis of dental eruptions, his age was estimated to be 44 months. He had received 219 hours of training in the behavioral task over a 15-month period, and prior to the flight he had been subjected to simulated Redstone launch profiles on the centrifuge at the U.S. Air Force Aerospace Medical Laboratory, Dayton, Ohio.

### Performance Apparatus and Task

Figure 4–1 shows the performance test panel, containing three lights and two levers, which was mounted perpendicular to the subject at waist level. The levers are approximately 1 inch in diameter and protrude 2¼ inches from the face of the panel. A force of 2 pounds was required to activate each lever so that it could not be depressed by the force of inertia accompanying launch.

The task, which is described in detail in reference 2, was one in which an intermittent or discrete avoidance procedure on the left lever was superimposed on a right-hand lever schedule which required continuous avoidance behavior. Each response by the subject on the right-hand lever postponed the occurrence of the next scheduled shock for 15 seconds and, as a consequence, a consistent and stable rate of responding was developed by which the animal could avoid shocks indefinitely.

In contrast to the continuous task, discrete avoidance employed a signal as a warning of impending shock if the correct response was not made. In the MR–2 flight, the warning signal was the illumination of the blue light. This light came on once every 2 minutes. However, a fixed time interval was not employed during training in order to eliminate the possibility of temporal conditioning. The time between the appearance of the blue light and the pressing of the left lever was the subject's reaction time.

During the flight the subject had to press the right lever at least once every 15 seconds and at the same time press the left lever within 5 seconds after each presentation of the blue light. A detailed description of the psychomotor programer operation is presented in section 4. Since redundancy in data collection was desired, five digital counters were included in the programing unit of the couch. These counted the responses on the right-hand lever, the blue-light presentations, responses on the left-hand lever, the number of shocks for failure to perform continuous-avoidance task, and the number of shocks for failure to make discrete-avoidance responses. Readings from these counters after flight verified the information obtained via telemetry and the onboard tape recorders.

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## Results and Discussion

From a behavioral viewpoint, this flight can be described as an experimental investigation to determine the effects upon learned behavior of exposure to the environmental distractions imposed by space flight. Following the flight, an investigation was made of those variables which could be studied in the laboratory without risk of injury to the subject. This investigation was made in an attempt to rule out certain extraneous factors that could possibly have affected the performance.

The first variables studied were the minor stresses on the subject that occurred immediately prior to the flight. These variables included the awakening after only 5 hours of sleep, installation of the physiological sensors including the suture ECG electrodes, and the nearly 9 hours of restraint prior to launch. The introduction of these variables raised questions as to the physical condition of the subject at the time of launch. It was suggested that the chimpanzee may have been fatigued. If this were true, then a reduced response rate on the continuous-avoidance behavior and an increased reaction time on the discrete task might be expected. However, because neither of these were observed and because the novelty and uniqueness of the flight itself could possibly compensate for subject fatigue, these stresses were again imposed upon the subject 2 weeks after the flight. The subject was kept awake on the 13th day after launch, was allowed to go to sleep at the usual time and was then awakened at 1:00 a.m. on the 14th day and subjected to the same activities as those during the countdown. It was then given a 17-minute trial in which both tasks were performed. The results of this test showed performance to be stable and unaffected. Thus, it was concluded that the physical condition of the subject resulting from preflight activities did not affect its in-flight performance.

With the exception of the noise and vibration accompanying the launch, the environmental factors associated with the remainder of the flight can be summarized in terms of the physical forces acting upon the subject during the launch, flight, and reentry into the earth's atmosphere. The magnitude, duration, and time of occurrence of these forces during the flight are shown in figure 5–1. The figure also shows the level of performance of the discrete-and-continuous-avoidance task during the flight. During the launch the animal was subjected to a maximum acceleration of 17g. This acceleration was followed by 6½ minutes of weightlessness. When the spacecraft started on its downward course into the denser atmosphere, its flight attitude was reversed so that during reentry the deceleration again imposed a transverse force of inertia which acted from back to front of the subject. Although the magnitude of the force was not so great as it was during launch, its duration was much longer; that is, there were accelerations of more than 14g for 5 seconds and more than 10g for 10 seconds.

The flight can be divided into three periods: launch accelerations, weightlessness, and reentry. In terms of performance of the continuous-avoidance task, the sharp reduction in response rate following launch was expected on the basis of the results obtained from previously exposing the subject to accelerations of 6g on the centrifuge at the U.S. Air Force Aerospace Medical Laboratory. Immediately following launch, the subject received his first shock. However, it is believed that this shock was due to a malfunction in the timing apparatus since analysis of the telemetry recording shows that the time between responses at this period of the flight was less than 15 seconds. Performance was not directly affected by weightlessness; however, exposure to the reentry decelerations was critical from the performance standpoint. A gradual decrement in the response rate for the continuous-avoidance task was observed, but reaction time was unaffected. (See table 5–I and fig. 5–1.)

It might appear that the high deceleration that accompanied reentry was responsible for the persistent decrement in performance of the continuous avoidance task; however, the launch accelerations and the weightless state (either individually or in combination) could also have accounted for the decrement. Moreover, since there was no information concerning performance following reentry, there was no way of determining whether the subject returned to normal response rates soon after the reentry portion of the flight was over or whether recovery was delayed. (See table 5–I and fig. 5–1.)

Reaction time, as measured by the discrete task, was unaffected. For the nine presentations of the blue light during the flight, the mean reaction time was 0.82 second which was slightly above the 0.80-second mean of his preflight performance. (See table 5–I and fig. 5–1.)

These flights represent a beginning in the measurement of animal behavior in space and as such, it is believed they can provide valuable data for the planning of further animal flight studies.

## Concluding Remarks

Performance of a two component avoidance task was measured on a chimpanzee that was flown on the

Mercury-Redstone 2 ballistic flight. As a result of this flight and the laboratory investigations which followed, it was concluded that the minor stresses imposed immediately prior to the flight, that is, prolonged wakefulness, physiological examination, and restraint, did not affect inflight performance. The accelerations accompanying launch and reentry were associated with a brief decrease in the response rates for the continuous avoidance task; however, the rate rapidly returned to normal and the immediate postlaunch rate showed no change from preflight control. This finding duplicated that following exposure to radial acceleration on the centrifuge at the Aerospace Medical Laboratory. Performance during weightlessness was steady and unimpaired. However, a sharp decrement in the response rate of the continuous task was noted following the acceleration that accompanied reentry. Performance of the discrete avoidance task was consistent and near the preflight mean throughout the flight.

## References


1. Rohles, Frederick H., Jr.: Behavioral Measurements on Animals Participating in Space Flight. Air Force Missile Development Center TN–60–5, Mar. 1960.
2. Belleville, Richard E., Rohles, Frederick H., Jr., Grunzke, Marvin E., and Clark, Fogle C.: Complex Avoidance Behavior in the Chimpanzee and its Applicability to the Study of Space Environments. Air Force Missile Development Center TR–60–27, Sept. 1960.

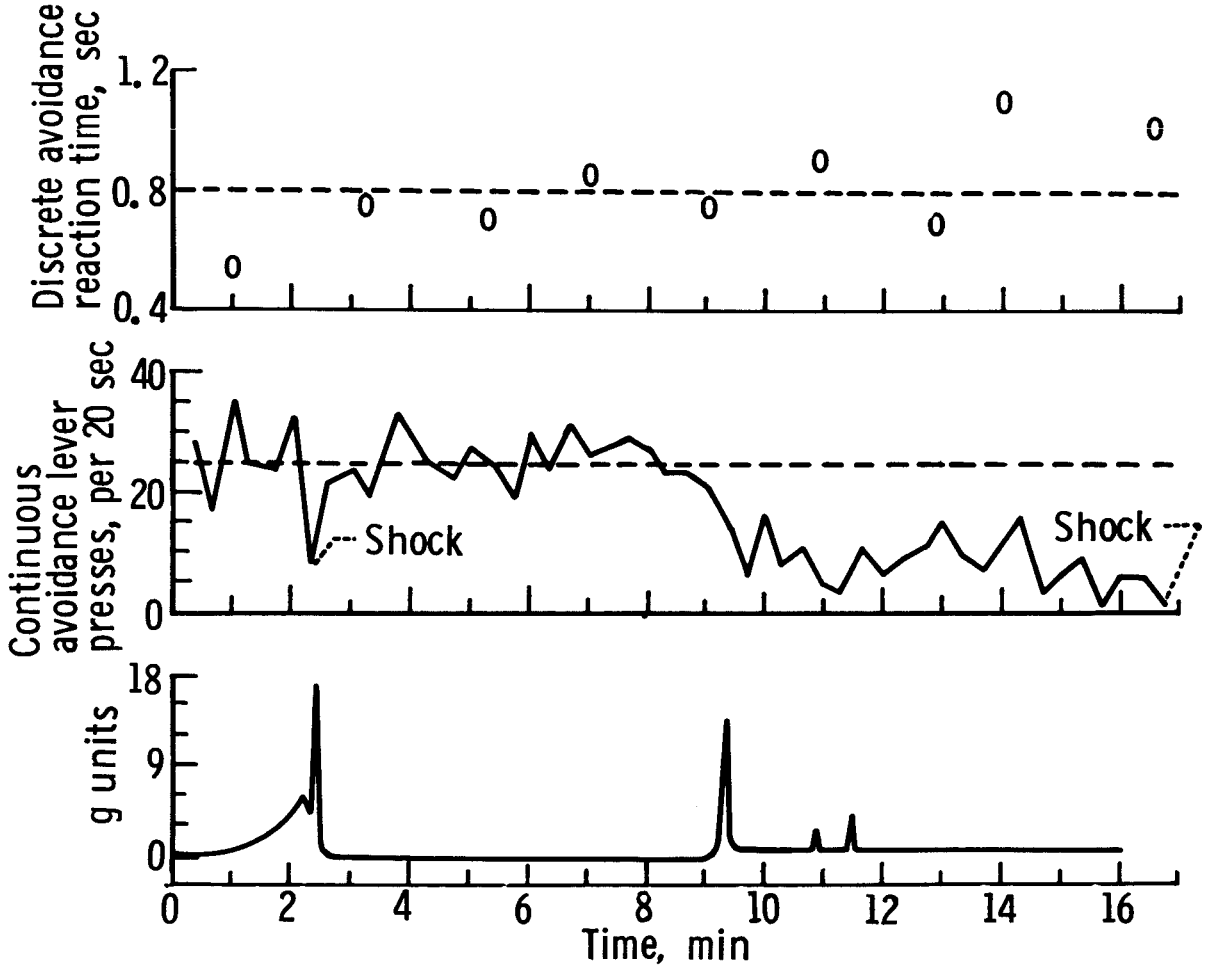




FIGURE 5–1.—Responses of the MR–2 flight animal to the blue light (classical avoidance giving reaction time) and the red light (Sidman test; a continuous monitoring task in which the lever must be pressed once every 20 seconds). The transverse dotted lines represent the average preflight responses of this subject. Discrete avoidance responses stay well within preflight means. The rate of pressing the continuous avoidance lever is normal during weightlessness and only falls significantly after exposure to the reentry acceleration.

TABLE 5-I.—*Raw performance data for continuous- and discrete-avoidance task in MR-2 flight*

| Time from launch, sec | Number of responses | | Number of shocks | | Discrete avoidance presentations | Duration of discrete avoidance reaction, sec |
|---|---|---|---|---|---|---|
| | Continuous avoidance lever | Discrete avoidance lever | Continuous avoidance | Discrete avoidance | | |
| 0 to 20 | 28 | | | | | |
| 21 to 40 | 17 | | | | | |
| 41 to 60 | 25 | | | | | |
| 61 to 80 | 34 | 1 | | | 1 | 0.55 |
| 81 to 100 | 24 | | | | | |
| 101 to 120 | 32 | | | | | |
| 121 to 140 | 7 | | 1 | | | |
| 141 to 160 | 23 | | | | | |
| 161 to 180 | 24 | | | | | |
| 181 to 200 | 19 | 1 | | | 1 | .75 |
| 201 to 220 | 33 | | | | | |
| 221 to 240 | 28 | | | | | |
| 241 to 260 | 25 | | | | | |
| 261 to 280 | 23 | | | | | |
| 281 to 300 | 27 | | | | | |
| 301 to 320 | 25 | 1 | | | 1 | .70 |
| 321 to 340 | 19 | | | | | |
| 341 to 360 | 30 | | | | | |
| 361 to 380 | 24 | | | | | |
| 381 to 400 | 31 | | | | | |
| 401 to 420 | 26 | 1 | | | 1 | .85 |
| 421 to 440 | 27 | | | | | |
| 441 to 460 | 29 | | | | | |
| 461 to 480 | 27 | | | | | |
| 481 to 500 | 24 | | | | | |
| 501 to 520 | 24 | | | | | |
| 521 to 540 | 21 | 1 | | | 1 | .75 |
| 541 to 560 | 15 | | | | | |
| 561 to 580 | 6 | | | | | |
| 581 to 600 | 16 | | | | | |
| 601 to 620 | 7 | | | | | |
| 621 to 640 | 10 | | | | | |
| 641 to 660 | 4 | 1 | | | 1 | .90 |
| 661 to 680 | 2 | | | | | |
| 681 to 700 | 11 | | | | | |
| 701 to 720 | 6 | | | | | |
| 721 to 740 | 9 | | | | | |
| 741 to 760 | 11 | 1 | | | 1 | .65 |
| 761 to 780 | 14 | | | | | |
| 781 to 800 | 9 | | | | | |
| 801 to 820 | 6 | | | | | |
| 821 to 840 | 10 | | | | | |
| 841 to 860 | 16 | 1 | | | 1 | 1.10 |
| 861 to 880 | 2 | | | | | |
| 881 to 900 | 5 | | | | | |
| 901 to 920 | 8 | | | | | |
| 921 to 940 | 0 | | | | | |
| 941 to 960 | 5 | | | | | |
| 961 to 980 | 5 | 1 | | | 1 | 1.00 |
| 981 to 1000 | 0 | | 1 | | | |

# 6. MEDICAL AND PHYSIOLOGICAL ASPECTS *of the* MR–2 FLIGHT

By William E. Ward,* and
William E. Britz, Jr.**

The chimpanzee subject was procured by the U.S. Air Force on July 9, 1959. It originated in the Cameroons, West Africa.

The animal was repeatedly given tuberculin tests with negative results and has remained in excellent health.

During the 18-month period from July 11, 1959, until January 31, 1961 (MR–2 flight), the subject received six complete, quarterly physical examinations. All of the findings were within normal ranges for the immature chimpanzee (ref. 1).

## Prelaunch Preparation of Primary, Secondary, and "Backup" Subjects

### Physical Examination and Diet

At T—26 hours 54 minutes (8:00 a.m. e.s.t.) following the prelaunch physical examination (see ref. 2 and table 6–I) the subject was placed on a low bulk, low gas-forming liquid diet (section 3).

At T—9 hours 36 minutes (1:15 a.m. e.s.t.) the subject was removed from its cage and taken to the medical van for flight preparation. It was given a physical examination and found to be in excellent condition for the flight.

### Data Collecting Methods

The following physiological parameters were measured: ECG (leads 1 and 3), respiration waveform, and rectal temperature. Prelaunch physiological data were recorded on Sanborn direct writing recorders; flight data were recorded on onboard tape and telemetered to ground stations and to recorders located on inflight aircraft.

*Captain, U.S. Air Force.
**Captain, Veterinary Corps, U.S. Air Force.

TABLE 6–I.—*Results of preflight and postflight physical examination conducted on MR–2 subject*

Subject: Immature male chimpanzee named "Ham"
Age: 3 years 8 months (approximately)
Clinical history: Subject has had no serious illness within 6 months prior the launch date

| Date | Time | Location | Weight, lb | Rectal temperature, °F | Blood pressure, mm/Hg | Pulse, beats/min | Respiration breaths/min | ECG | X-ray |
|---|---|---|---|---|---|---|---|---|---|
| Jan 30, 1961 | 8:00 a.m. e.s.t. | Animal complex, Cape Canaveral. | 37 | 99.8 | 122/98 | 104 | 28 | Normal | Normal |
| Jan 31, 1961 | 1:15 a.m. e.s.t. | Animal complex, Cape Canaveral. | 37.25 | 96.4 | 138/110 | 140 | 32 | Normal | Normal |
| Jan 31, 1961 | 4:30 p.m. e.s.t. | Recovery ship | | *99 | 130/90 | 120 | 32 | | |
| Feb 1, 1961 | 8:10 a.m. e.s.t. | Grand Bahama Island | | 98.8 | 130/85 | 100 | 30 | Normal | |
| Feb 2, 1961 | 8:00 a.m. e.s.t. | Animal complex, Cape Canaveral. | 35.25 | 98.8 | 110/84 | 92 | 24 | Normal | Normal |
| Feb 7, 1961 | 10:00 a.m. m.s.t. | Holloman Air Force Base, N. Mex. | 38.75 | 99.4 | 128/98 | 104 | 32 | Normal | Normal |
| Feb 14, 1961 | 1:00 p.m. m.s.t. | Holloman Air Force Base, N. Mex. | 38.0 | 100.0 | 148/120 | 124 | 30 | Normal | Normal |

*Axillary

*Electrocardiogram.*—The ECG was detected by three electrodes (fig. 6–1). Two electrodes were made of male and female snap fasteners grasping steel sutures 0.28 inch in diameter, which were implanted under the skin of the chest as described in reference 3. (See figs. 6–1 and 6–2). A stainless-steel-mesh fluid

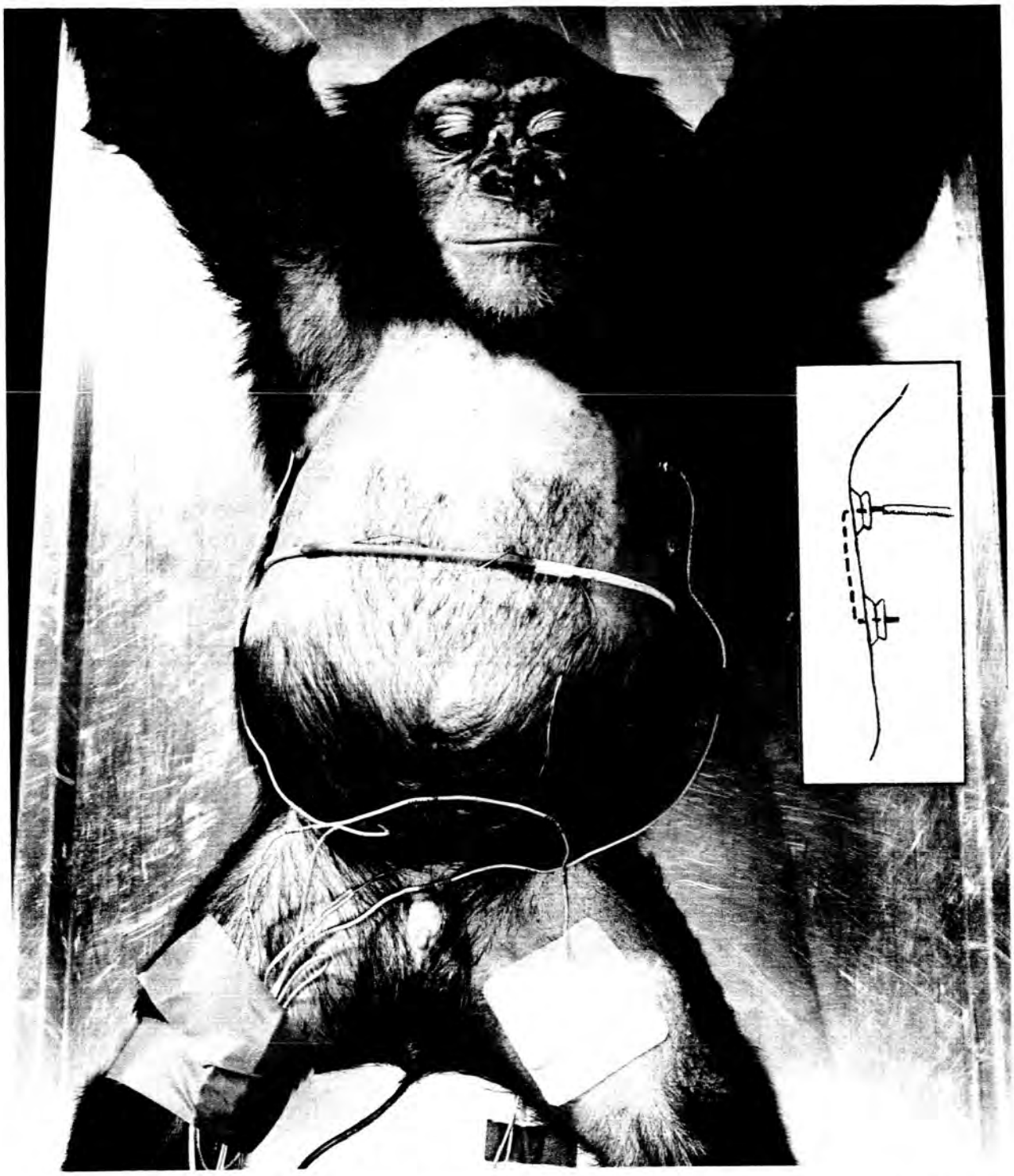
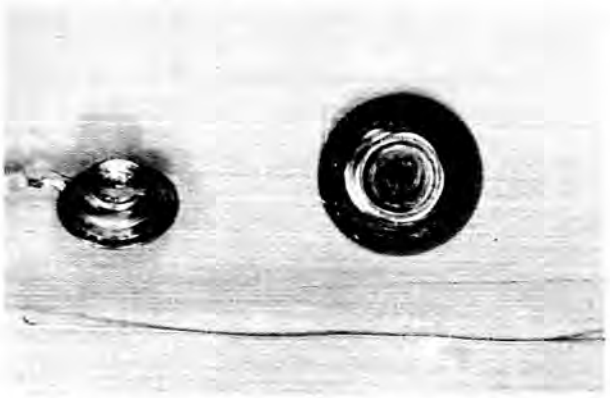
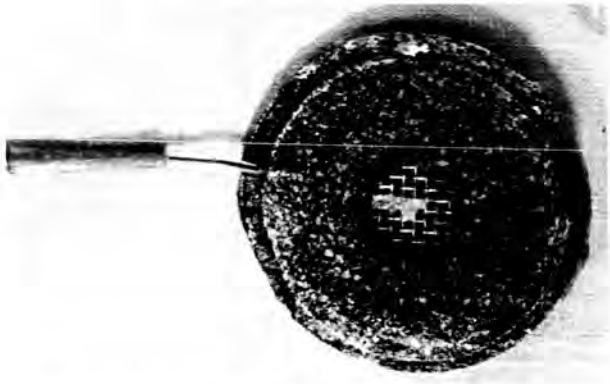


FIGURE 6–1.—Subject following installation of the rectal thermistor, ECG electrodes, and copper sulfate pheumograph. The insert to the right depicts how the wire suture used for the ECG pickup is clipped between one pair of snap fasteners (see fig. 6–2) and passes under the skin to be brought out at the other.

electrode (bentonite paste as a conductor) of the type to be used in the manned flights was applied to the left medial thigh (fig. 6–2).



(a) Enlargement showing male and female snap fasteners and wire used for the suture electrodes.



(b) Wire mesh electrode with a cork surround that holds the mesh away from the skin and provides a space for electrode jelly.

FIGURE 6-2.—Steel suture electrodes.

The areas of attachment were first clipped and cleaned with alcohol. Then tincture of Merthiolate was applied. The suture electrodes were attached to each side of the subject transverse to the fifth and sixth ribs and parallel to the anterior axillary plane. The wires were inserted through the female snap fasteners and then under the skin of the subject. The wires extended, subcutaneously and parallel to the surface of the skin for 1½ inches. The ends of the sutures were then brought out of the skin through female snap fasteners and secured with male fasteners to which electrical leads had been attached. The fluid electrode was applied to the medial aspect of the left thigh with bentonite paste. The electrode was secured with adhesive tape.

*Respiration.*—The respiration sensor (fig. 6–3) was a flexible plastic and rubber tube of ⅛-inch inside diameter, 3/16 inch outside diameter, and length of approximately 1 inch less than the chest circumference of the subject.

A 3-inch rubber section of the tube was filled with a 15 percent solution of copper sulfate. Electrical connections from each end of this section led to a resistor-capacitance coupled transistorized amplifier with limited band pass and was connected to a subcarrier oscillator of the spacecraft telemetry system. The transducer was placed on the subject so that the sensing element was over the sternum and midway between the xyphoid process and the manubrium (fig. 6–1). Resistance changes from respiratory movements provided an excellent signal response for data recording.

*Body temperature.*—Rectal temperature was measured with an internal (esophageal-rectal) temperature probe as described in reference 3. The probe was inserted approximately 8 inches into the rectum and held in place by tape applied to the buttocks.

Heart rates prior to launch were checked by counting the QRS complexes of lead 3 for 1 minute in every 10 minutes. (Lead 3 was chosen because there was less electrical interference on this channel than on

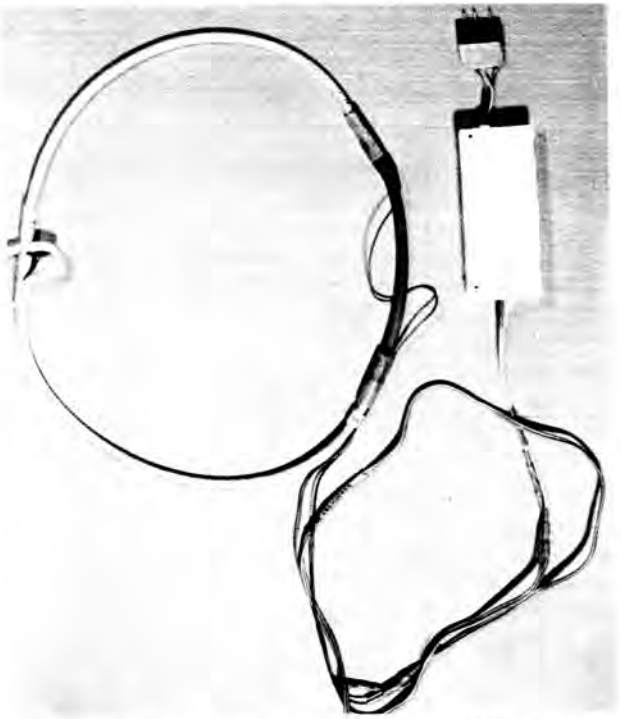


FIGURE 6-3.—Respiratory sensor (pneumograph) consisting of a rubber tube filled with saturated copper sulfate solution whose resistance will vary as the tube is stretched by breathing movements. A resistance-capacitor coupled transistorized amplifier (top right) eliminated drift by passing only the variations whose frequency is greater than ½ cycle per second.

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lead 1). Heart rate during the flight was determined by counting all QRS complexes per minute for each minute of the flight. Prelaunch respiration rates were determined by counting waveform peaks for 1 minute in every 10 minutes. Respiration rate during the flight was compiled by counting the number of waveform peaks per minute and recording totals at the end of each minute of flight. Body temperature values were recorded at 10-minute intervals during the prelaunch period and at the end of each minute during the flight.

## Results

### Physiology

The physiological data from the MR–2 flight are presented in figure 6–4. Time on the abscissa scale is in minutes from launch. Total flight time was 16 minutes 39 seconds.

*Prelaunch heart rate.*—For the period 8 hours prior to launch, the mean heart rate was 94 beats per minute, a rate slightly lower than the mean established for the subject in a previous test (see table 6–II). However, during the early morning period the subject was lying quietly in the couch. At approximately T—8 hours and again at T—7 hours the subject was engaged in a 15-minute psychomotor work performance.

*Launch and flight heart rate.*—From lift-off to T+1 minute, the heart rate was 126 beats per minute. During the third minute of flight, there was an increase in heart rate to 147 beats per minute (ECG

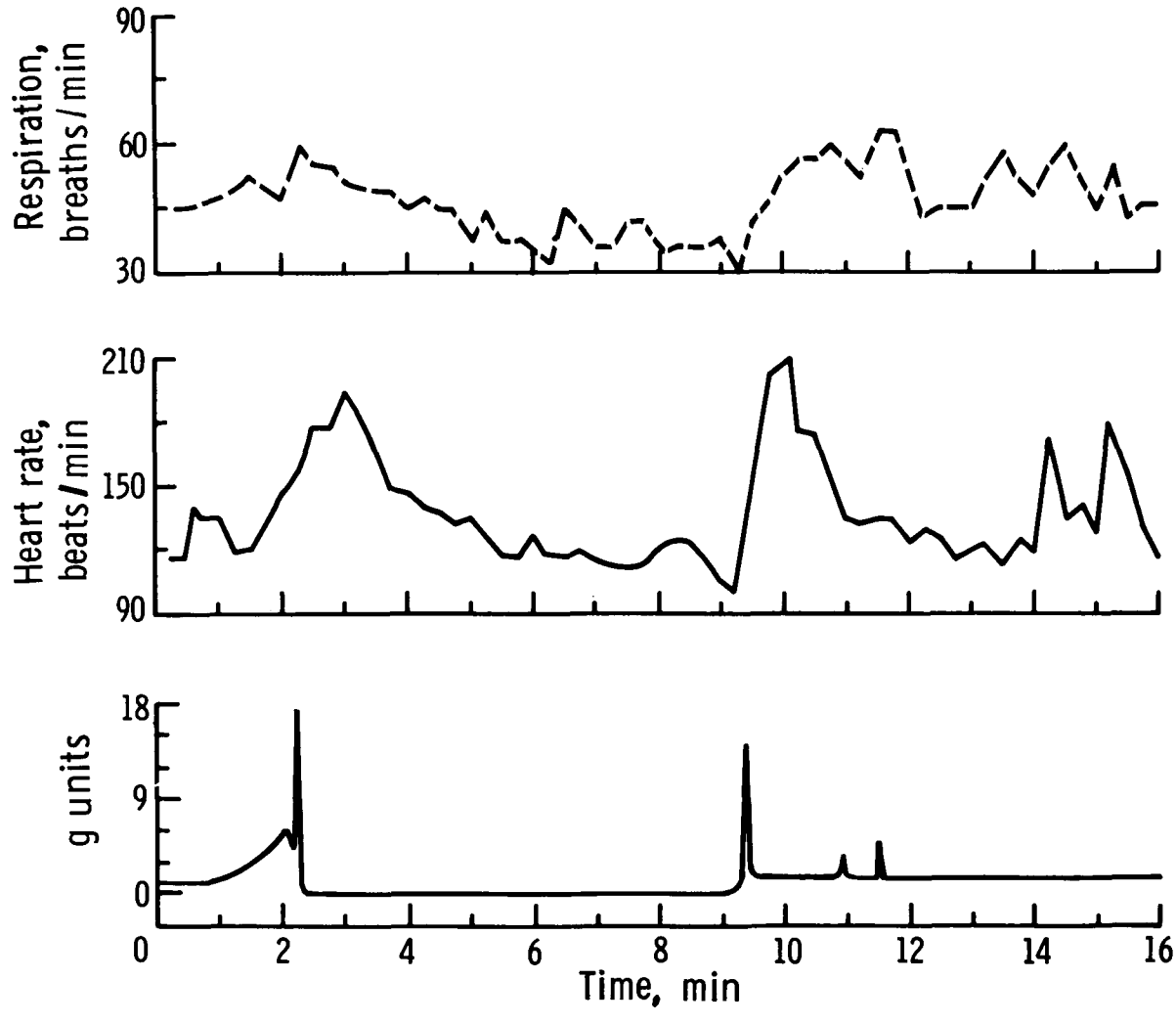



FIGURE 6–4.—Heart and respiratory rates (based on 10-sec intervals) throughout the MR–2 flight. Rates fall to preflight values during the weightless state. (For preflight control data, see table 6–II.)

telemetry was lost during this period for 10 seconds). Peak acceleration was experienced at T+2.3 minutes; then acceleration traces returned to zero. From T+3 to T+4 minutes there was a rise in the mean heart rate to 158 and then a gradual decline during the weightless period. Figure 6–5 is an example of the in-flight data taken during the weightless state. This period lasted approximately 7 minutes. Reentry peak acceleration occurred at T+9 minutes 35 seconds. From T+10 to T+11 minutes there was a dramatic rise in the heart rate to 173 beats per minute; the heart rate then fell slowly to 119 beats per minute at T+14 minutes. In one 10-second period from T+10 to T+11 during the peak reentry acceleration, 34 beats were recorded. If this rate had been sustained it would have constituted a rate of 204 beats per minute from T+10 to T+11. Heart rate was approximately 130 beats per minute at landing (muscle noise artifact prevented a full count).

### Recovery and Postflight Observations

The MR–2 flight lasted approximately 17 minutes, and landing occurred approximately 130 nautical miles beyond the planned point. After the arrival of spacecraft onboard the recovery ship, the LSD Donner, the animal couch was taken out, its top removed, and the subject was examined by an Air Force veterinarian. According to his report, the animal was in good condition, even though the inside of the couch was hot and humid.

The veterinarian removed the subject from the couch and performed the postflight physical examination. A 30-cc blood sample was taken for postflight blood count and chemistry studies.

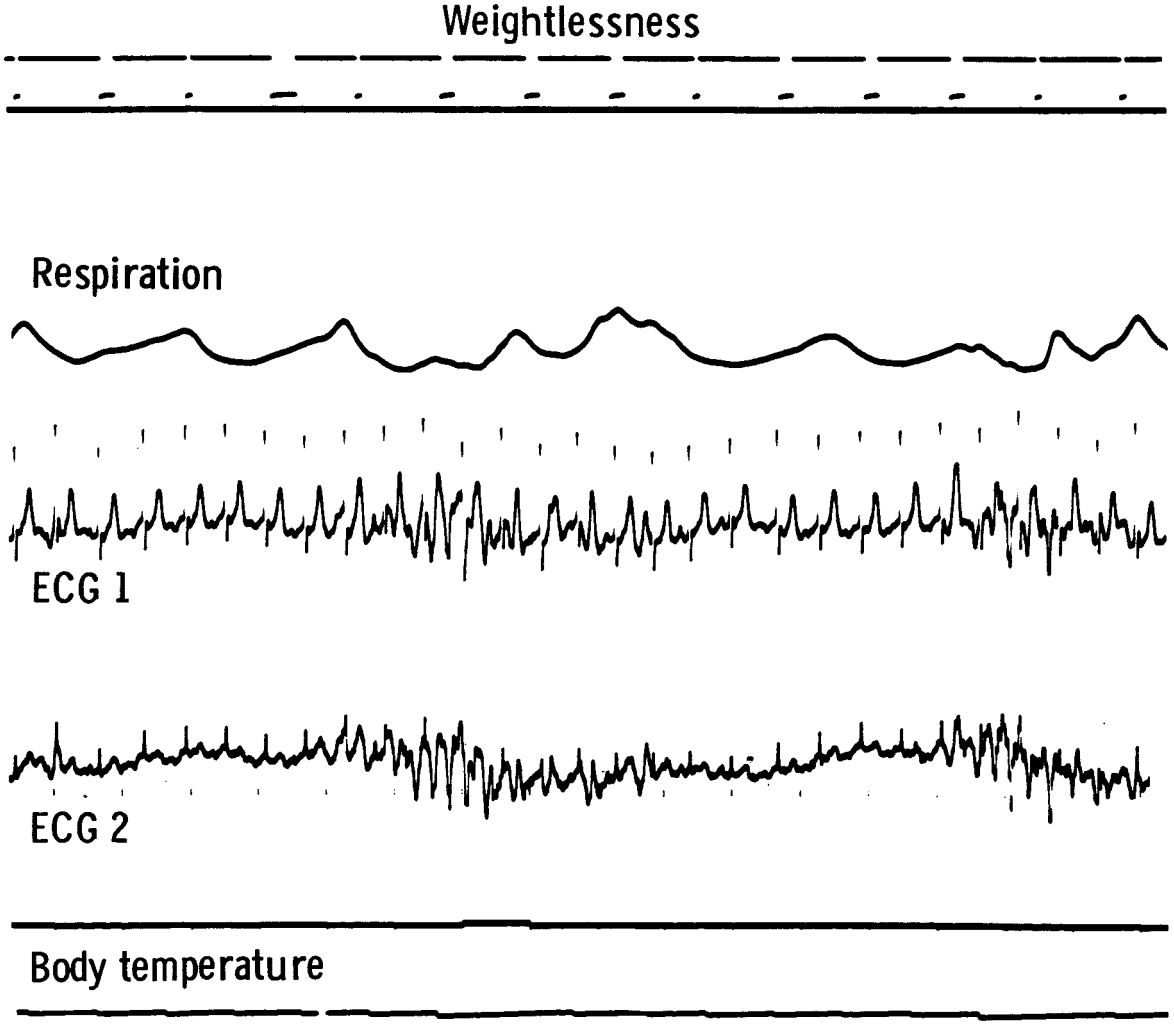



FIGURE 6–5.—Portion of the inflight telemetered MR–2 data showing the records obtained from the electrocardiogram and respiratory sensors at an altitude of approximately 100 nautical miles during the weightless state.

TABLE 6–II *Heart and respiration rates*

[Control data established 4 days before launch]

| | |
|---|---|
| Heart rate: | |
| Mean, beats/min | 121 |
| Standard deviation, beats/min | 3.2 |
| Range, beats/min | 100 to 154 |
| Respiration rate: | |
| Mean, breaths/min | 44 |
| Standard deviation, breaths/min | 4.8 |
| Range, breaths/min | 22 to 72 |

The subject appeared slightly dehydrated and somewhat exhausted immediately after the flight. Despite the dehydration no change in the hematocrit was observed. However, there was a 5.37-percent loss in the total body weight. This loss was to be expected in view of the fact that the subject had received no food or water for approximately 16 hours. The same change has been observed in controlled temperature-humidity studies conducted at the Aeromedical Research Laboratory. The subject responded to sounds; he was alert; and no incoordination of limb, head, or body movements was detected. All reflexes were normal. Ophthalmoscopic examination showed no changes from the observations made during the preflight examination. A small abrasion was present on the bridge of the nose, but it was insignificant and appeared to be self-inflicted. A small amount of dried vomitus (5 to 10 cc), containing what was thought to be traces of blood, was noted in the couch. No abnormalities were noted during the auscultation of heart and lungs.

After completion of the physical examination, the subject was placed in a small cage provided on the ship. He was then fed fruit, given water when he wanted it, and allowed to rest for the remainder of the night.

The following morning the subject was transported to the forward medical facility at the Grand Bahama Islands. There, he was given a complete physical examination. (See table 6–III.) The only abnormality noted at this time was a slightly dehydrated appearance, and the animal appeared physically exhausted.

The subject was then transported from the forward medical station back to Cape Canaveral and was allowed to rest for the remainder of the day.

On the second day after the flight (February 2) the subject was given another complete physical examination and found to be in good condition. (See table 6–III.) Following this physical examination, he was fully instrumented and placed in the flight couch for a postflight psychomotor evaluation test.

On February 4 the subject was returned to the Aeromedical Research Laboratory at Holloman Air Force Base. He was given a complete physical examination

TABLE 6–III.—*Clinical and laboratory results before and after the MR–2 flight*

[MR–2 launched at 11:54 a.m. e.s.t. on Jan. 31, 1961]

| | Jan. 30 | Jan. 31[a] | Feb. 2 | Feb. 7 | Feb. 14 |
|---|---|---|---|---|---|
| Cardiac auscultation | Normal | Normal | Normal | Normal | Normal |
| Pulmonary auscultation | Normal | Normal | Normal | Normal | Normal |
| Condition of subject | Normal | Fatigued | Normal | Normal | Normal |
| Laboratory results: | | | | | |
| Urinalysis | Normal | Normal | Normal | Normal | Normal |
| Fecal analysis | Normal | Negative for blood—normal. | Normal | Normal | Normal |
| Complete blood count: | | | | | |
| Red blood cells, millions per $mm^3$ | 7.35 | 5.23 to 5.21 | [b] 5.75 | 4.29 | 5.04 |
| Hemoglobin, grams | 13.0 | 13 | [b] 12.0 | 13.32 | 12.95 |
| Hematocrit, percent | 46 | 41 | [b] 45 | 45 | 44 |
| White blood cells, per $mm^3$ | 13,700 | 16,000 | [b] 12,500 | 16,350 | 12,800 |
| Neutrophiles, percent | 31 | 94 | [b] 14 | 35 | 28 |
| Lymphocytes, percent | 69 | 4 | [b] 84 | 60 | 69 |
| Monocytes, percent | ..... | 1 | ..... | 1 | 1 |
| Eosinophiles, percent | ..... | ..... | [b] 2 | 3 | 2 |
| Basophiles, percent | ..... | ..... | ..... | 1 | ..... |

[a]Immediately after recovery.
[b]Blood sample taken on Feb. 3.

on February 7 (1 week after the flight), and again on February 14 (2 weeks after the flight). The results were completely within normal ranges, and the subject was in excellent condition.

## Discussion

During launch acceleration, there was a rise in both heart and respiratory rates followed by a gradual decline during the weightless state. At 1½ minutes after peak reentry acceleration there was a marked rise in respiration rate, far exceeding the rise during initial launch. Respiration rate declined during the next 2 minutes, then rose slightly, and finally exhibited a downward trend prior to landing. Following the rise during and immediately after launch acceleration, the heart rate declined rather slowly for the first 3 minutes of the weightless state. It then stabilized, rising during reentry and falling again with the return to 1g (fig. 6–4). During the physical examination conducted approximately 4½ hours after impact, the heart rate was 120 beats per minute, and respiration was 32 breaths per minute. No significant change in body temperature was noted.

The subject was without water for 16 hours from the time of placement in the couch until the postflight examination. Upon observation 16 hours after this examination, it appeared to be slightly dehydrated. It had access to food and water when it wished, from the time of recovery; nevertheless, when weighed 44 hours after the flight there was a 5.3-percent loss from his initial body weight. Reference 4 states that a 5-percent body weight loss in man represents significant dehydration. Young chimpanzees who are deprived of water and food and restrained in a chair for 20-hour periods show the significant loss of 4-percent of body weight. Hence, the data on the flight subject suggest that it was significantly dehydrated.

Heart and respiration rates, and the body temperature of the subject during the MR–2 flight were well within the normal range established for chimpanzees during the control temperature-humidity tests.

Probably the most dramatic and significant change seen in the MR–2 subject was in the postflight hematology. The differential white blood cell count showed an extreme reversal of the neutrophile-lymphocyte ratio. (See table 6–III.) The blood sample taken during the 24-hour preflight physical examination showed a ratio of 31-percent neutrophiles to 69-percent lymphocytes (4,247 total neutrophiles to 9,453 total lymphocytes). These values are essentially normal for immature chimpanzees. The sample taken on board the recovery ship immediately following recovery (2 hours, 44 minutes after the flight) showed a ratio of 94-percent neutrophiles to 4-percent lymphocytes (15,040 total neutrophiles to 800 total lymphocytes). All other hematological findings, except the eosinophile count, which is discussed subsequently, were within normal ranges. Similar, though less severe, changes have been observed following 20-hour controlled temperature-humidity studies at the Aeromedical Research Laboratory. Three days after the flight, the ratio was slightly higher than normal: 14-percent neutrophiles to 84-percent lymphocytes (1,750 total neutrophiles to 10,500 total lymphocytes). One week after the flight, the ratio was again within normal ranges: 35-percent neutrophiles to 60-percent lymphocytes (5,273 total neutrophiles to 9,810 total lymphocytes).

After the flight, there was a significant change in the total circulating eosinophile count. Normally, the count of this subject was more than 100 per mm. Immediately after the flight, there was a complete absence of eosinophiles in the circulating blood.

Biochemical analyses of plasma and urine samples obtained before and after the flight indicate a level of 17 hydroxycorticosteroid activity of 50 micrograms per 100 cc of plasma. These results represent an increase of approximately 36 micrograms per 100 cc of plasma during the MR–2 flight. Thus, a marked pituitary-adrenal response is indicated.

Fecal samples immediately after recovery and 2 days after the flight were negative for blood by the guaiac test. These results eliminate the possibility of gastrointestinal hemorrhage of any magnitude. It is presumed that the 5 to 10 cc of dried vomitus noted on opening the couch was a result of either eructation or retching during the postlanding period while the spacecraft was subjected to wave action pending recovery. The postflight urine samples contained traces of albumin which persisted for 2 days following recovery. These traces indicate that there may have been severe oliguria.

## Concluding Remarks

The MR–2 flight, conducted on January 31, 1961, was characterized by good telemetry which permitted a thorough study of the physiological reactions of the chimpanzee subjected to this unusual environment.

Heart- and respiration-rate recovery from acceleration following a weightless period of almost 7 minutes was slower than recovery following launch acceleration.

The subject's heart and respiration rates and body temperature did not exceed ranges established for

young chimpanzees in a thermally neutral environment.

Body weight loss, hematological findings, and biochemical analyses of plasma and urine samples taken after recovery indicate that the total prelaunch, flight, and recovery experience had exposed the animal to significant stress.

## References


1. Cook, James E., Fineg, Jerry, and Miksch, Eldon D.: Physiological Base-Line Studies of Zoological Specimens. Phase I: Hematological Values of Immature Chimpanzees. Air Force Missile Development Center TN–60–9, July 1960.
2. Stingely, Norman E.: Countdown and Procedures for Project Mercury Flight MR–2 (Chimpanzee Subject). Air Force Missile Development Center TR–61–20, June 1961.
3. Wheelwright, Charles D.: Physiological Sensors for Use in Project Mercury. NASA TN D–1082, 1962.
4. Adolph, E. R.: Physiology of Man in the Desert. Interscience Publishers, Inc. (New York), 1947.

# 7. SUMMARY OF RESULTS *of the* MR–2 FLIGHT

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The original questions posed by the results of the MR–2 flight have been answered by manned flights prior to the publication of these papers. Nevertheless, the flight has some real significance. In it, a high-order primate was subjected to the stresses of the prelaunch operations, launch, flight, reentry, landing, and recovery from the ocean. Despite these various stresses, few measurable physiological and behavioral changes were noted. When compared with a photograph (fig. 7–1) taken before the flight, figure 7–2 indicates the animal's good condition onboard ship only a few hours after recovery. As previously described in references 1 to 3 there was a significant lag after launch in the recovery of heart rate to normal values. The heart rate rose to 158 beats per minute between T+3 to T+4. It required approximately 4 minutes of weightlessness for it to return to the preflight values. After the tachycardia accompanying the reentry acceleration following the period of weightlessness, the heart rate returned slowly to normal values. However, during this period, drogue parachute opening, main parachute opening, and impact were interspersed in the low acceleration field and these events may have deferred the return of the rate to normal. The respiration rate was not greatly disturbed by the launch accelerations and returned to preflight values during weightlessness, varying from a low of 22 to a high of 72 breaths per minute with a mean throughout the flight of 44 breaths per minute. The environmental control system of the Mercury spacecraft performed so well that the subject's temperature was essentially unchanged throughout the flight.

Of interest is the neutrophile-lymphocyte ratio shift, which is believed to be a result of the exposure to the stresses of launch preparation, flight, and postlanding period in the ocean awaiting recovery. Upon recovery and release from the spacecraft, the white-blood-cell count showed a ratio of 94-percent neutrophiles to 4-percent lymphocytes with a total count of 16,000 white blood cells. Seventy-two hours later, there were 14 neutrophiles to 84 lymphocytes. By February 7, nine days after flight, the neutrophile-



FIGURE 7–1.—Chimpanzee subject before MR–2 flight.

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FIGURE 7-2.—Chimpanzee subject after MR-2 flight.

lymphocyte ratio had returned to the normal 35-percent of neutrophiles (see table 6-III). This shift in the ratio which is found during stress has previously been described in reference 4 in the analysis of blood samples obtained from chimpanzee subjects in studies exposing them to high temperature and humidity.

The excellent performance of the chimpanzee on the two required tasks was gratifying. Of the two shocks received during the flight, only one was deserved. The reliability of the subject on the continuous avoidance task shows that this type of work can be monitored by a higher primate under these space-flight conditions. In controlled laboratory experiments on a centrifuge, chimpanzee subjects have been exposed to accelerations of 6 g in simulating the launch of the Redstone vehicle. At that time, a decrement in performance on a continuous avoidance task was noted; therefore, the decrement observed following launch and reentry was to be expected. However, the decrement after launch was followed by recovery to prelaunch values within approximately 1 minute. There was also a decrement following reentry. Although determination of its significance must await the results of further flights, it is possible that it was related to oscillation of the spacecraft prior to stabilization by the deployment of the drogue parachute.

## References


1. Von Beckh, Harold J.: Human Reactions During Flight to Acceleration Preceded or Followed by Weightlessness. Aerospace Medicine, vol. 30, June 1959, pp. 391-409.
2. Koustnetzov, A. G.: Some Results of Biological Experiments in Rocket and Sputnik II. Journal of Aviation Medicine, vol. 29, 1958, p. 781.
3. Gazenko, O. G., and Yazdovsky, V. J.: Some Results of Physiological Reactions to Space Flight Conditions. 12th IAF Congress (Washington, D.C.), Oct. 1961.
4. Archibald, Erwin R., and Ward, William E.: Chimpanzee Temperature-Humidity Tolerance Tests—Control Tests at 80° F, 50 Percent Relative Humidity. Air Force Missile Development Center TR-61-11, Apr. 1961.

# 8. MA–5 OPERATIONS

By Norman E. Stingely,* and
John D. Mosely, D.M.V.**

## Prelaunch Activities

For the Mercury-Atlas 5 (MA–5) orbital mission, the animal launch operations at Cape Canaveral, Florida, began October 29, 1961, with the arrival of 3 chimpanzees and 12 scientific and technical personnel. Two chimpanzees and eight personnel were already at Cape Canaveral as of October 29, 1961, having been employed in previous Project Mercury system tests.

One practice countdown was conducted by the medical preparation team. It consisted of preparing the subject and couch, but it did not include inserting them into the spacecraft or connecting them with the spacecraft environmental control system (ECS) or electrical system. Seven additional preliminary countdowns were accomplished. In these countdowns, the couch and subject were either connected to the spacecraft internal ECS and electrical system from the outside or inserted into the spacecraft and attached to the systems. Four of the countdowns were systems tests, one was a flight acceptance composite test, one was a launch simulation and radio frequency compatibility test, and one was a simulated flight.

In addition to these practice countdowns, 53 training sessions served to maintain animal performance proficiency.

## Flight Preparation and Insertion

### T—2 Days (November 27, 1961)

*7:30 a.m.*—Complete physical examinations were given to the three primary subjects. The physical examination was the same as for the MR–2 flight. (See section 3.)

*1:30 p.m.*—All three primary subjects underwent 270 minutes of behavioral training. The duration and the test simulated that of the programed flight, and control data were collected during this time.

At the completion of the physical examination and behavioral training, the flight and backup animals were chosen (section 3). It is of interest to note that the MR–2 flight animal was one of the three final flight candidates.

### T—1 Day (November 28, 1961)

*7:30 a.m.*—All vans were checked to see that the necessary animal preparation equipment and supplies were available and in their proper place. Blood and urine samples for metabolic studies were collected and processed. These samples were later analyzed for use in the study of the physiological responses of chimpanzees to the stresses imposed by space flight.

All subjects were placed on a diet and feeding schedule. At approximately T—26 hours (7:30 a.m.), each received a few commercial food pellets, one banana, and 500 cc of water. No more food or water was given to the flight animal until recovery when it was given food and water when it wanted them.

A check of all test equipment was initiated (section 3).

*1:00 p.m.*—Restraint suits and couch attachment tabs were selected and fitted to the flight and backup subjects. They were then placed in their respective flight couches and fitted to them. The urine collection and drinking water systems were serviced.

*11:00 p.m.*—Physiological sensors were applied by the same procedure as is described in section 6.

*11:24 p.m.*—A urinary catheter was inserted and the retention bladder was inflated. The subject was then diapered, placed in his prefitted suit (see fig. 8–1), and readied for arterial and venous catheterization. The arterial catheter was inserted into the anterior tibial artery and the venous catheter into the right saphenous vein. The blood-pressure sensor was attached to the catheter immediately upon insertion, and a slow flow of physiological normal saline solution containing heparin was initiated. The subject was then zipped and laced into the couch. A psychomotor stimulus plate was attached to the sole of each foot. Finally, the blood-pressure sensor and the respiration-sensor amplifier were attached (fig. 8–1). The urine

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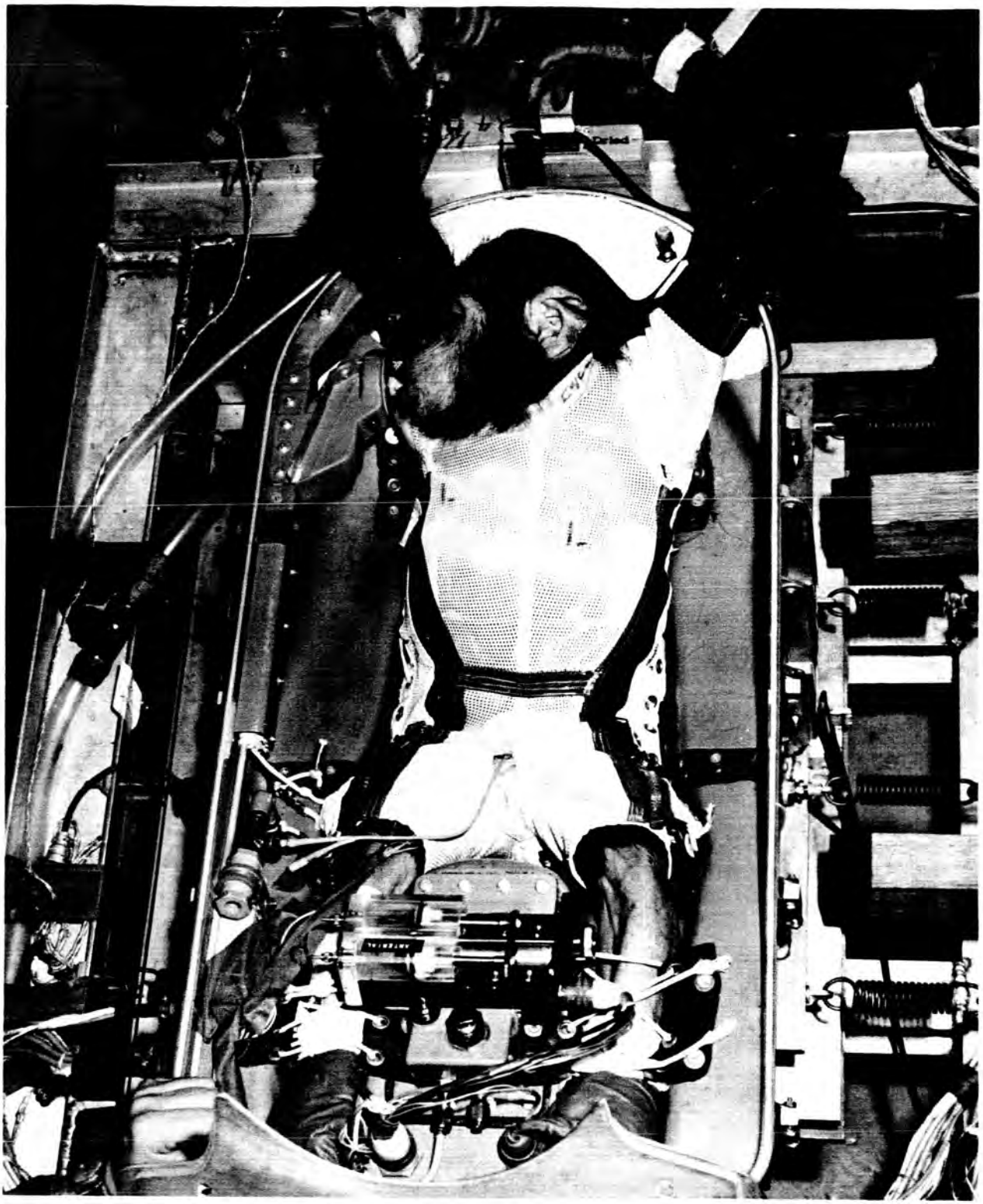


FIGURE 8-1.—Subject in flight couch in the act of taking a fluid reward. Animal diapered with urinary catheter inserted. Pressure transducers appear between the legs mounted transversely to the pressurized water bottles.

flow was directed into a container (100-cc capacity) to be saved for postflight analysis.

Launch Day (November 29, 1961)

*2:28 a.m.*—The flight subject and couch base were moved from the medical to the transfer van where the same procedures were carried out as are described for the MR–2 flight in section 3.

*3:10 a.m.*—Couch leak was carried out the same as MR–2 (section 3).

*3:21 a.m.*—The transfer van was directed to move to the launch pad and arrived at 3:41 a.m.

*4:00 a.m.*—The subject and couch were moved up the gantry and inserted into the spacecraft. Hatch closure was completed at 7:25 a.m. and the gantry was taken away. At 8:00 a.m., an 85-minute hold occurred, while the gantry was returned and the hatch was opened to set a telemetry switch. The count was resumed at 9:25 a.m. The psychomotor performance apparatus was turned on at T—2 minutes.

*10:07:57 a.m.*—Lift-off occurred.

## Monitoring

The monitoring procedures at Cape Canaveral are described in section 3. Since this was an orbital flight, worldwide monitoring of the subject occurred at Mercury Control Center (MCC) and its 17 subsidiary stations distributed on a belt around the earth. The stations stretch across the Atlantic Ocean and are situated on Grand Bahama Island, Grand Turk Island, Bermuda, Grand Canary Island, and in a ship in mid-Atlantic. The network includes African sites at Kano, Nigeria, and Zanzibar; a ship in the Indian Ocean; Australian stations at Muchea and Woomera; Canton Island in mid-Pacific; and Kauai Island, Hawaii. The system also has stations at Point Arguello, California; Guaymas, Mexico; White Sands, New Mexico; Corpus Christi, Texas; and Eglin Air Force Base, Florida.

Data from the subject as well as from the numerous spacecraft systems were transmitted back to earth in real-time. The MCC received continuous readouts from Bermuda and Grand Turk Island; whereas all other stations, after making their observations of data from the spacecraft systems and subject, immediately reported their opinions back to MCC where decisions were made as to the conduct of the flight. There was real-time surveillance of the subject for 77.4 percent of the total flight time.

Data collection in addition to the monitoring of records was conducted at the Cape Telemetry II station. Other data sources for postflight evaluation of the flight subject were onboard recorders and onboard photography of the subject.

## Flight Characteristics

The acceleration in the longitudinal axis of the launch vehicle which was imparted to the subject in a transverse plane is presented in figure 8–2. From lift-off, the accelerations increased to 6.8g at T+2 minutes 11 seconds. The booster engines were then jettisoned and the acceleration dipped to 1.6g. The sustainer engine continued until T+5 minutes and reached a peak of 7.6g. At burnout, the acceleration returned to zero gravity.

Spacecraft separation from the launch vehicle was uneventful with no large oscillation occurring, and the turn-around of the spacecraft was satisfactory. The spacecraft entered an orbit inclined 32.5° to the equator, with a perigee of 99.5 statute miles, an apogee of 147.4 statute miles, and an orbit period of 88 minutes and 26 seconds.

The couch inlet temperature was 63.5° F at lift-off and gradually increased throughout the flight. Soon after the beginning of the second orbital pass, the couch inlet air and cabin temperatures started to rise rapidly making continued flight questionable. However, towards the end of this orbit the inlet air temperature leveled off; and since the rectal temperature remained within normal limits, a three-orbit flight could have been accomplished. The couch inlet air temperature with the snorkel valve open was 87.5° F at landing, and 9 minutes after landing reached its maximum of 92.0° F.

The couch-pressure controls worked satisfactorily. The environmental control system was designed so that the subject breathed 100-percent oxygen from lift-off until descent when the snorkel opened at 14,300 feet. As the craft went to altitude, the pressure was reduced to 6 psig at 3 minutes 20 seconds after launch, and pressure reduction continued as a linear function until it reached its minimum of 5.05 psig at 3 hours after launch. The pressure then returned to ambient just prior to landing.

Mechanical trouble precluded completion of the scheduled three orbits. Mercury Control Center requested that the California Mercury Network station initiate retrofire at 3 hours and 15 seconds after launch. Initial reentry deceleration began at T+3 hours 10 minutes, reached a maximum of 7.8g at T+3 hours 13 minutes 12 seconds, and declined to 1.2g at T+3 hours 15 minutes 36 seconds (fig. 8–2). The drogue parachute deployment caused a pulse of 0.4g and the main parachute deployment caused a

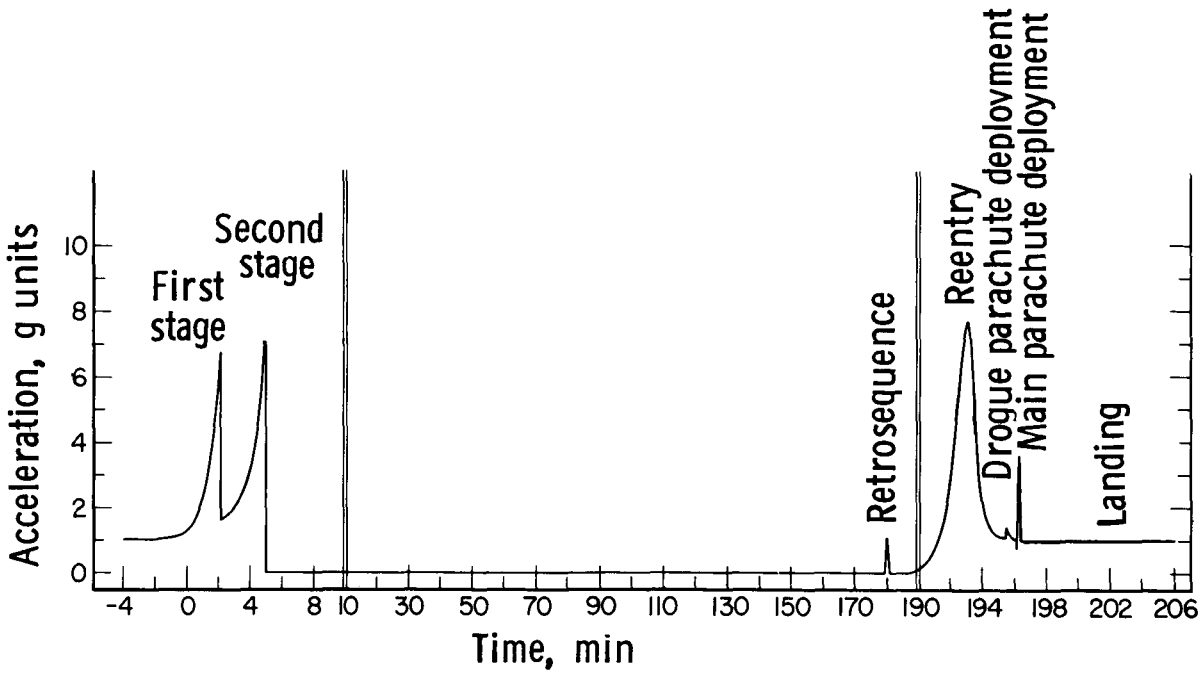



FIGURE 8-2.—Relation between accelerations transverse to the subject and time during the MA-2 flight.

3.6g deceleration. Lateral and normal accelerations during flight were negligible.

## Recovery and Postflight Periods

Recovery support was available from Cape Canaveral across the Atlantic to the Canary Islands. If the unexpected had happened and an abort had occurred on the launch pad, point recovery, a highly coordinated land, sea and air effort, would have been called upon to retrieve the spacecraft and subject. This recovery unit extends for a radius of 12 miles from the launch site.

The normal recovery force consisted of airborne surveillance and 18 ships distributed along four probable impact areas. These four areas were designed to meet spacecraft recovery needs in the following four possible contingencies: First, if the spacecraft did not go into orbit, and second, third, and fourth, in the event of normal termination with reentry after the first, second, or third orbits, respectively.

Landing occurred 3 hours and 21 minutes (1:29 p.m. e.s.t.) after lift-off. The spacecraft landed 200 miles south of Bermuda at a point 28°57′ N. latitude by 66°04′W. longitude. The scout aircraft pilots sighted the spacecraft as it descended and maintained observation until the recovery ship, U.S.S. *Stormes*, arrived at 4 hours 37 minutes after launch and retrieved it. The spacecraft was immediately opened and the couch with the subject in it was removed at 7 hours 45 minutes after launch.

During the delay in getting the subject and couch out of the spacecraft, the subject damaged several sensor items and inflicted minor injury to himself by breaking through his nylon restraint panel and removing an inflated urine catheter. The broken sensors such as ECG leads and the conductor to the respiration sensor, did not affect the results of the flight since flight data accumulation had ceased before the subject damaged the sensors.

The subject was removed from the recovery ship at approximately 7:00 a.m., November 30, 1961, and taken directly to the Kindley Air Force Base hospital at Bermuda, where a complete physical examination was made. The animal remained in Bermuda for 24 hours and was returned to Cape Canaveral on December 1, 1961, at which time another complete physical examination was given. It was returned to Holloman Air Force Base, New Mexico, on December 7, 1961.

# 9. PERFORMANCE ASPECTS *of the* MA–5 FLIGHT

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Marvin E. Grunzke,** and
Herbert H. Reynolds**

In the first of the two flights described in sections 2 to 7, a chimpanzee was placed through a ballistic flight trajectory. During the flight, the animal had to perform a continuous and discrete motor task that had been learned on the ground. Details of this flight relative to the performance have been reported in section 5. In the second flight, a chimpanzee performed a complex multiple operant task while orbiting the earth twice. The details of the performance aspects of that flight are presented in this section.

## Subject

The subject was a 42-pound male chimpanzee, Enos, whose age was estimated to be 63 months. Prior to flight, he had been exposed to simulated launch accelerations on the centrifuge at the University of Southern California (see ref. 1). As discussed in reference 2, he also had served as a subject for a laboratory model of a 14-day flight in which he performed the same tasks as he did during the orbital flight. He had received a total of approximately 1,263 hours of training over a 16-month period; 343 hours of this training was accomplished under restraint conditions in a laboratory model of the actual couch used during the flight.

## Performance Test Panel

As shown in the photograph in figure 4–2, the performance test panel consisted of three miniature inline digital displays (IDD) and three levers. The IDD's were centered on a line 4 inches above the bottom of the panel; the center display was mounted on the midpoint of this line and the two additional displays were mounted on center lines which were 3.8 inches to the left and right of this point. Centered and mounted 2.8 inches below each display was a 1-inch-diameter aluminum lever. Each lever protruded 2.25 inches beyond the face of the panel and required a 2-pound force for activation.

A pellet feeder was also incorporated into the panel. This consisted of a tube or magazine which served as a "hopper" for 106 specially designed food pellets, weighing 0.5 gram each. A spring maintained pressure on the single "column" of pellets in the tube, and one pellet at a time was delivered by means of a solenoid which pushed the pellets from the tube into two small plastic fingers which were located on the face of the panel below and to the right of lever 3. The pellets were loaded into the tube on the left side of the panel. The tube curved behind the panel and terminated at the plastic fingers. (See fig. 4–2.)

For water reinforcement, a lip-lever drinking tube, described in reference 3, was mounted in the couch to the right of the subject's head. A small green lamp was mounted either above or below this tube and when illuminated served to cue the subject that water was available when he bit the lever (figs. 9–1 and 9–2). Water for this device was kept under pressure against a valve on the lip-lever by a bottle of compressed air. Details relevant to the operation and design of both the liquid and pellet feeders have been reported in reference 4.

The method for programing the tasks, the procedure for delivering the electrical shock, and the shock level were the same as in the MR–2 flight. The task programer units were transistorized and housed behind the performance test panel. Their design is summarized in section 4. Three techniques were used, simultaneously, to collect the performance data. In

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FIGURE 9–1.—Orbital flight couch showing the triangular upper section of the pressurized drinking reservoir. On the side of the couch close to the animal's head is a nipple connected by a hidden tube to the reservoir. The animal squeezes the nipple to obtain a water reward. The green signal light is seen close to the nipple. (See also figure 11–1.)



FIGURE 9–2.—An early training assembly showing the animal turning its head to obtain a drink. The green signal light appears just above the nipple.

one, data were routed through four points on a multiplex unit and the commutated data were transmitted to ground receiving stations. These data were also retained on magnetic tape on the onboard recorder. In the second, the performance information was coded by voltage controlled oscillators and continuously recorded on two subchannels of the onboard recorder tape. Since space and weight were critical, a single digital counter was mounted behind the performance panel and served as a final method for collecting the performance data. The total of all responses was recorded on this counter.

## Performance Task

The task required performance on a five-component, multiple-operant conditioning schedule; the details of the training procedures are presented in reference 5. A description of the apparatus is presented in section 4. The first two tasks, continuous avoidance (CA) and discrete avoidance (DA), were the same as in the MR–2 flight. Performance of the continuous avoidance task was measured in terms of the number of lever presses in a 30-second period; the discrete avoidance task was essentially a visual monitoring task and performance was measured in terms of reaction time. Figure 9–3 shows how the responses to this task were recorded and telemetered on the cumulative response channels.

The third task required the subject to perform on an operant conditioning schedule involving differential reinforcement of a low rate (DRL). Water was used as the reinforcer or reward. Performance of the DRL task was measured in terms of the time that the subject waited between reward lever presses. An example of the response pattern is shown in figure 9–4.

The fourth task was a fixed ratio (FR) reinforcement program for food reward. Performance on this

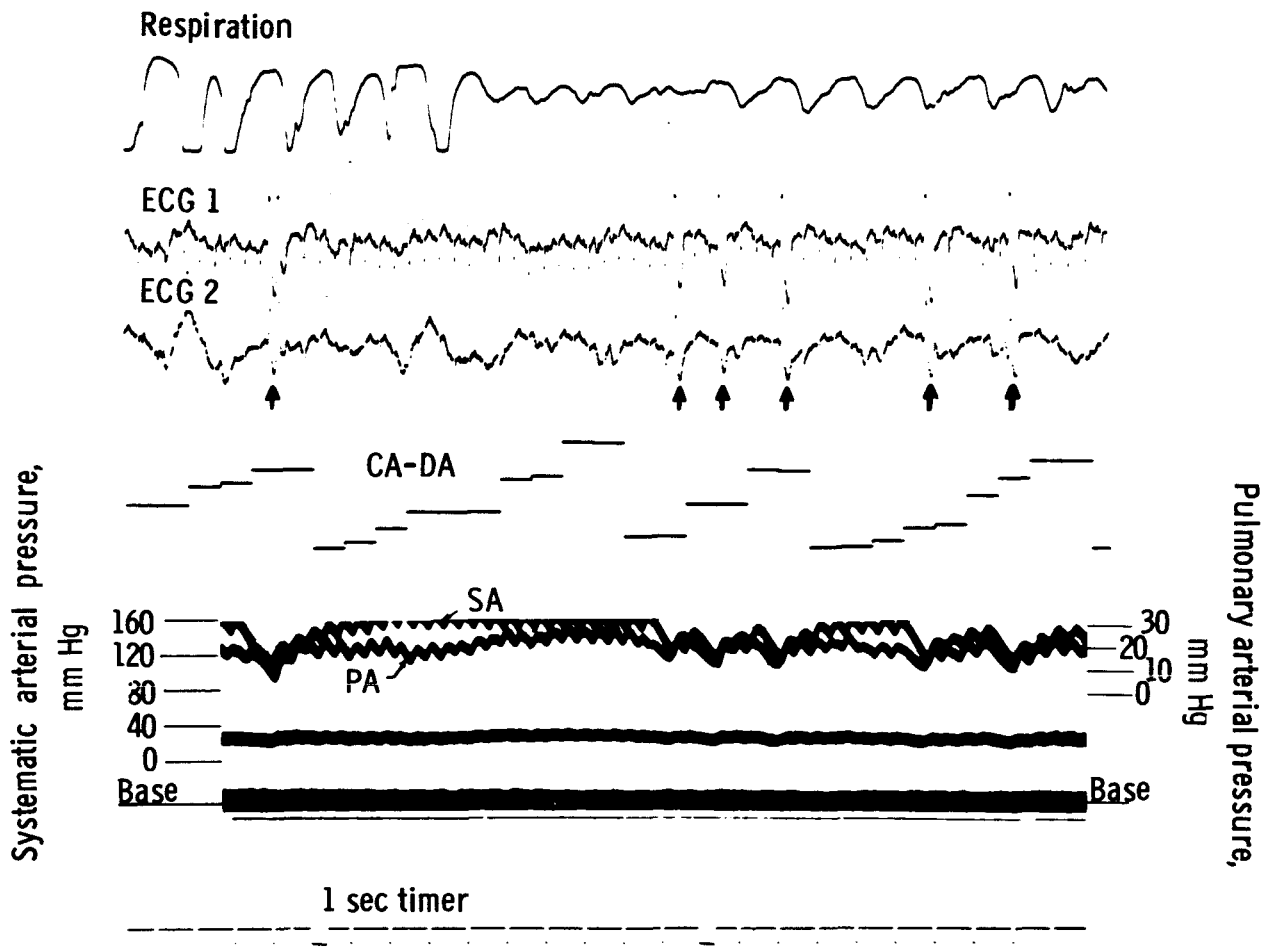



FIGURE 9-3.—Composite diagram of records for T+138 minutes. The bottom traces the records of the 1- and 10-second timer. A section of the pressure records from the oscillograph follows. Immediately above the baseline is the tracing of pulmonary arterial pressure registered with a galvanometer of low sensitivity. Above this again and running together are the records of pulmonary and systemic arterial pressure. There are a number of premature ventricular contractions which cause insignificant and transient falls in the pressure records. They mirror the events in the electrocardiographic traces above, where the incidence of these contractions is noted by the arrows. Above the ECG traces is the respiratory record and below (CA–DA) is the cumulative record of responses on the right-hand lever to the continuous avoidance task.

schedule was measured for each pellet reinforcement separately in terms of the time required for each set of 50 lever presses. An example of the response pattern is shown in figure 9–5.

The fifth task consisted of the 18 oddity problems shown in table 9–I.

One problem at a time was presented to the subject by means of the three IDD's. The level of performance of this task was measured in terms of discrimination accuracy by the following formula:

$$\text{Efficiency} = \frac{18}{\text{Total discriminations}}$$

## Flight Results

The CA-DA task was turned on 2 minutes before launch and the subject performed on all components of the program from that time until 10 minutes after landing. The time during the flight in which each task was in effect is presented in table 9–II.

The chimpanzee's performance of the CA-DA task is presented in figure 9–6, which is a comprehensive chart presenting the tasks in their temporal relationship to each other and to the major acceleration events of the flight. As depicted in the graph, acceleration constitutes the bottom trace. The traces above show the performance during the first session in the course

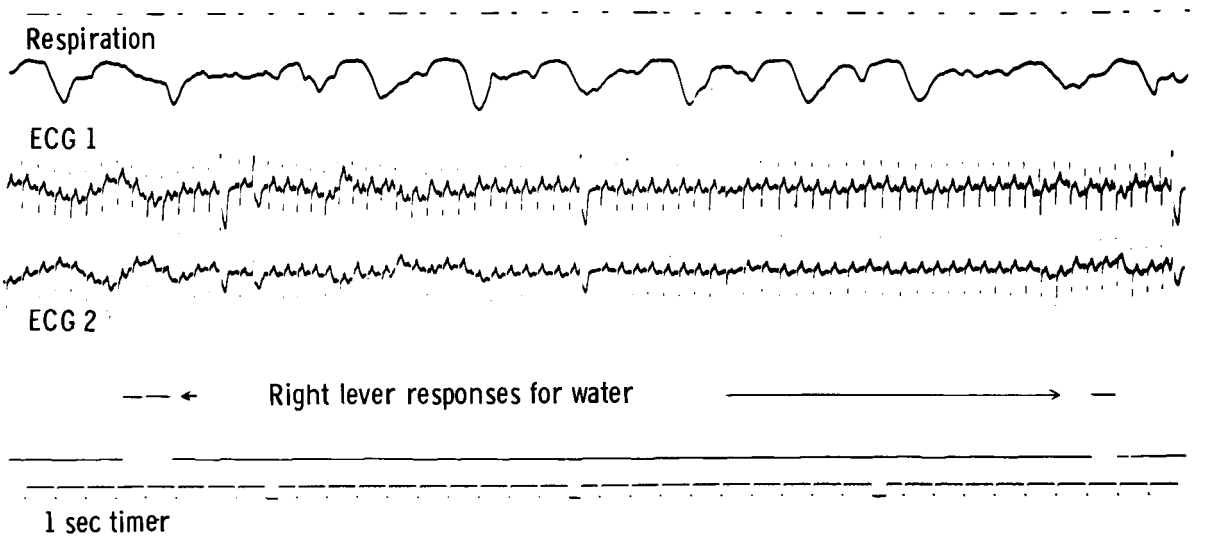



FIGURE 9-4.—A portion of the onboard record taken after approximately 1½ hours of weightlessness. The 1-second time is broken at 10-second intervals by a longer timing bar. Two right lever responses for water are spaced 29 seconds apart. The two electrocardiogram leads show a number of premature ventricular contractions which have no effect on the performance, above these again is the respiratory record.

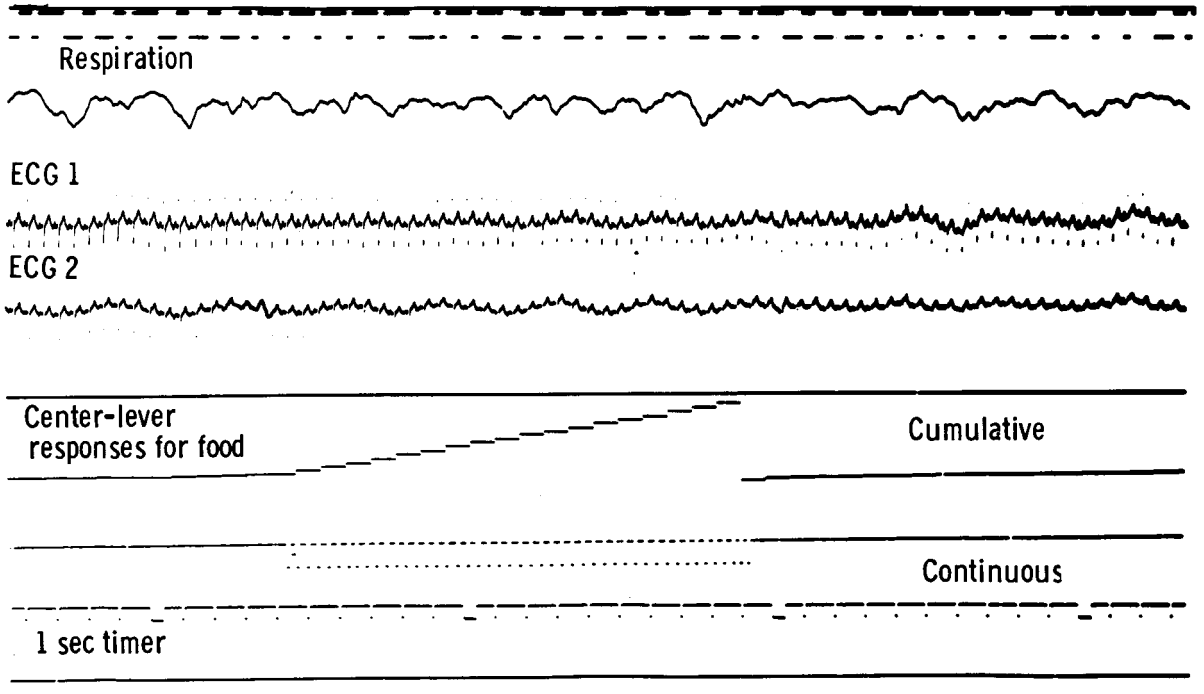



FIGURE 9-5.—Onboard record of responses for food pellets showing performance after approximately 30 minutes of weightlessness. After the 1- and 10-second timing line, reading from below upward, comes the response on the center lever as recorded onboard on the continuous data channel. On the record, the animal made 50 responses in order to obtain a banana-flavored pellet. Above this, a cumulative record of the responses on the center lever is shown by the upward stepping of a steady, uniform response performance, which is at the subject's normal rates. Above these responses come the two ECG records and the respiration trace. Above these again is the record of timing of events on the onboard tape.

of the launch accelerations, during sessions 2 and 3 when the subject was weightless, and finally during reentry. While performing the CA-DA tasks, the subject received only two shocks—one for the CA task during the first session and one for the DA task during the fourth session. While performance of the

TABLE 9–I.—*Series of 18 oddity problems presented during flight*

| Problem No. | Symbol on display | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| 1 | ○ | △ | ○ |
| 2 | △ | △ | ○ |
| 3 | ○ | ○ | □ |
| 4 | △ | ○ | ○ |
| 5 | △ | ○ | △ |
| 6 | □ | □ | △ |
| 7 | ○ | □ | □ |
| 8 | △ | □ | □ |
| 9 | △ | △ | □ |
| 10 | □ | ○ | □ |
| 11 | □ | △ | △ |
| 12 | ○ | □ | ○ |
| 13 | ○ | ○ | △ |
| 14 | ○ | △ | △ |
| 15 | △ | □ | △ |
| 16 | □ | ○ | ○ |
| 17 | □ | △ | □ |
| 18 | □ | □ | ○ |

CA was variable during and immediately following launch (session 1), the subsequent sessions show a stable response rate within the range of the preflight mean plus or minus one standard deviation. The mean response time for 29 presentations of the blue light was 1.49 seconds which was somewhat slower than the preflight mean of 1.03 seconds. It should also be pointed out that eight presentations of the blue

TABLE 9–II.—*Temporal sequence of performance tasks*

| Task | Time from launch, min | Duration of task, min | Total accumulated time, min |
|---|---|---|---|
| CA–DA | −2 to 17 | 20 | 20 |
| Timeout | 18 to 23 | 6 | 26 |
| DRL–20 | 24 to 33 | 10 | 36 |
| Timeout | 34 to 39 | 6 | 42 |
| FR–50 | 40 to 49 | 10 | 52 |
| Timeout | 50 to 55 | 6 | 58 |
| Oddity | 56 to 65 | 10 | 68 |
| CA–DA | 66 to 80 | 15 | 83 |
| Timeout | 81 to 86 | 6 | 89 |
| DRL–20 | [a] 87 to 96 | 10 | 99 |
| Timeout | 97 to 102 | 6 | 105 |
| FR–50 | 103 to 112 | 10 | 115 |
| Timeout | 113 to 118 | 6 | 121 |
| Oddity | 119 to 128 | 10 | 131 |
| CA–DA | 129 to 143 | 15 | 146 |
| Timeout | 144 to 149 | 6 | 152 |
| DRL–20 | 150 to 159 | 10 | 162 |
| Timeout | 160 to 165 | 6 | 168 |
| FR–50 | 166 to 175 | 10 | 178 |
| Timeout | [b] 176 to 181 | 6 | 184 |
| Oddity | 182 to 191 | 10 | 194 |
| CA–DA | [c] 192 to 206 | 15 | 209 |

[a] Completed first orbit at Launch T+90 min
[b] Completed second orbit at Launch T+180 min; retrorockets fired at Launch T+181 min
[c] Impact at sea occurred at T+202 min

light were made during the first session, whereas only seven were made during each of the three following sessions. The raw performance data for the combined CA-DA tasks are shown in table 9–III.

An overall picture of the performance on the three sessions of the DRL task is presented in figure 9–6. For this task, the interresponse times were somewhat higher than those established under the preflight conditions. Table 9–IV, which presents the raw performance data for the three DRL sessions during flight, shows each DRL response during each of the three 10-minute periods that the task was in effect; for example, during session 1 the first response occurred after 23 seconds, and the second response, after 33 seconds. During session 1, the subject made 14 responses and earned 13 water reinforcements (7 cc's of water for each reinforcement); during session 2, sixteen responses were made and sixteen reinforcements received; and during session 3, twenty responses were made and eighteen of these were rewarded. Figure 9–4, taken from the record made onboard, shows a typical delayed response after 1½ hours of weightless flight.

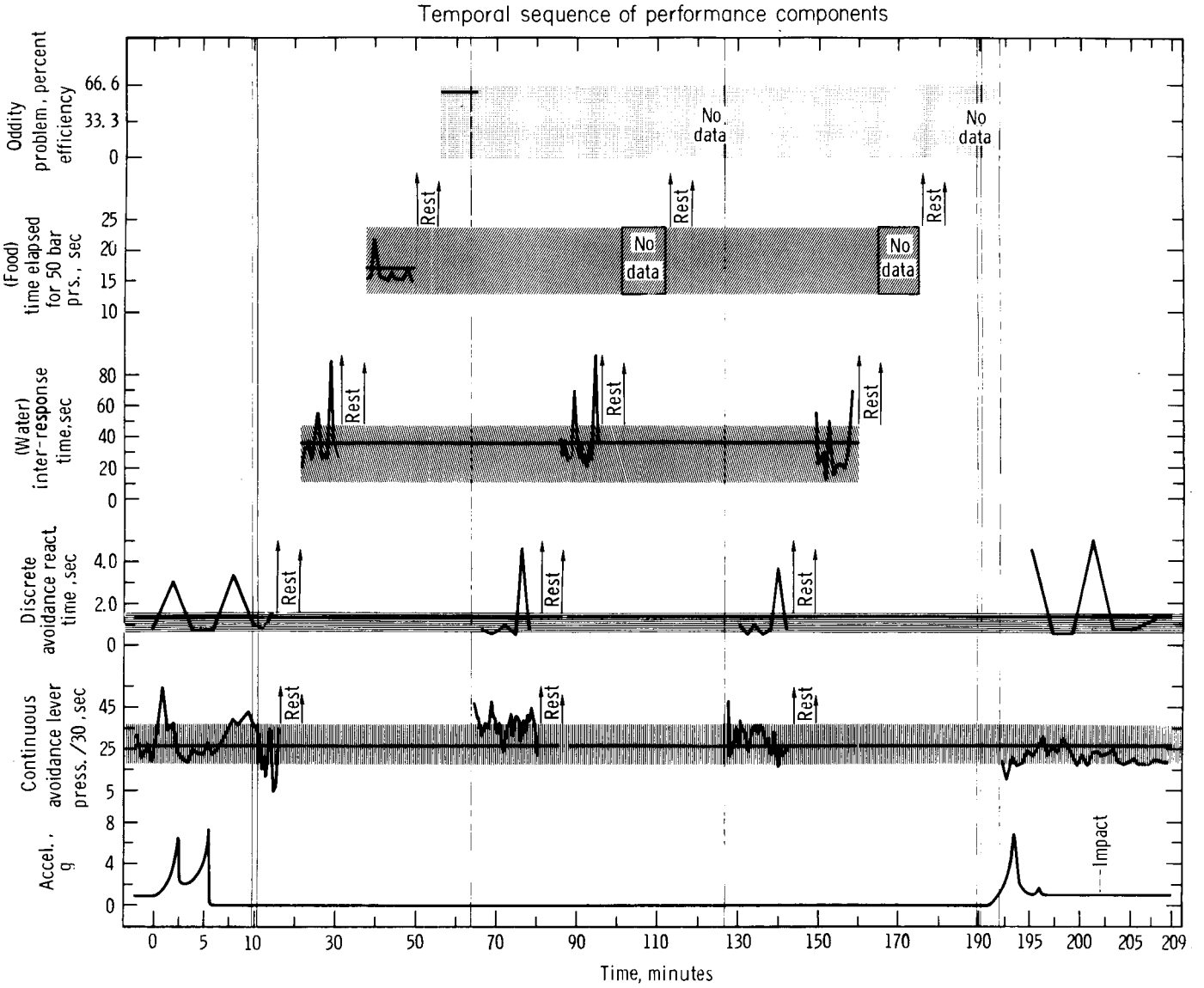



FIGURE 9-6.—Diagram summarizing the performance data obtained during the MA-5 flight and showing the sequence of events. Next to the abscissa is the record of acceleration transverse to the animal. The broad shaded bands indicate one sigma deviation in each direction from the subject's preflight performance norm for any particular task. The transverse heavy line represents the arithmetic mean of the animal's performance for the tasks during the flight.

TABLE 9–III.—*Raw performance data for continuous- and discrete-avoidance tasks in MA–5 flight*

| Time from launch, min | Number of responses | | Number of shocks | | Discrete avoidance presentations | Duration of discrete avoidance reaction, sec |
|---|---|---|---|---|---|---|
| | Continuous avoidance lever | Discrete avoidance lever | Continuous avoidance | Discrete avoidance | | |
| **FIRST SESSION** | | | | | | |
| −2.0 to −1.5 | 32 | | | | | |
| −1.5 to −1.0 | 21 | | | | | |
| −1.0 to −0.5 | 27 | | | | | |
| −0.5 to −0 | 19 | 1 | | | 1 | 0.75 |
| 0 to 0.5 | 34 | | | | | |
| 0.5 to 1.0 | 55 | | | | | |
| 1.0 to 1.5 | 34 | | | | | |
| 1.5 to 2.0 | 37 | 1 | | | 1 | 3.10 |
| 2.0 to 2.5 | 23 | | | | | |
| 2.5 to 3.0 | 20 | | | | | |
| 3.0 to 3.5 | 19 | | | | | |
| 3.5 to 4.0 | 25 | 1 | | | 1 | .75 |
| 4.0 to 4.5 | 23 | | | | | |
| 4.5 to 5.0 | 23 | | | | | |
| 5.0 to 5.5 | 28 | | | | | |
| 5.5 to 6.0 | 23 | 1 | | | 1 | .75 |
| 6.0 to 6.5 | 25 | | | | | |
| 6.5 to 7.0 | 31 | | | | | |
| 7.0 to 7.5 | 35 | | | | | |
| 7.5 to 8.0 | 39 | 1 | | | 1 | 3.40 |
| 8.0 to 8.5 | 37 | | | | | |
| 8.5 to 9.0 | 40 | | | | | |
| 9.0 to 9.5 | 43 | | | | | |
| 9.5 to 10.0 | 37 | 1 | | | 1 | 1.00 |
| 10.0 to 10.5 | 34 | | | | | |
| 10.5 to 11.0 | 29 | | | | | |
| 11.0 to 11.5 | 15 | | | | | |
| 11.5 to 12.0 | 21 | 1 | | | 1 | .75 |
| 12.0 to 12.5 | 12 | | | | | |
| 12.5 to 13.0 | 30 | | | | | |
| 13.0 to 13.5 | 35 | | | | | |
| 13.5 to 14.0 | 21 | 1 | | | 1 | 1.50 |
| 14.0 to 14.5 | 5 | | | | | |
| 14.5 to 15.0 | 7 | | | | | |
| 15.0 to 15.5 | 38 | | 1 | | | |
| **SECOND SESSION** | | | | | | |
| 64.0 to 64.5 | 48 | | | | | |
| 64.5 to 65.0 | 40 | | | | | |
| 65.0 to 65.5 | 40 | | | | | |
| 65.5 to 66.0 | 32 | | | | | |
| 66.0 to 66.5 | 33 | 1 | | | 1 | 0.75 |
| 66.5 to 67.0 | 38 | | | | | |
| 67.0 to 67.5 | 35 | | | | | |
| 67.5 to 68.0 | 37 | | | | | |
| 68.0 to 68.5 | 48 | 1 | | | 1 | .56 |
| 68.5 to 69.0 | 41 | | | | | |
| 69.0 to 69.5 | 40 | | | | | |
| 69.5 to 70.0 | 33 | | | | | |

TABLE 9–III.—*Raw performance data for continuous- and discrete-avoidance tasks in MA–5 flight*—Continued

| Time from launch, min | Number of responses | | Number of shocks | | Discrete avoidance presentations | Duration of discrete avoidance reaction, sec |
|---|---|---|---|---|---|---|
| | Continuous avoidance lever | Discrete avoidance lever | Continuous avoidance | Discrete avoidance | | |
| **SECOND SESSION** | | | | | | |
| 70.0 to 70.5 | 38 | 1 | | | 1 | .75 |
| 70.5 to 71.0 | 30 | | | | | |
| 71.0 to 71.5 | 24 | | | | | |
| 71.5 to 72.0 | 36 | | | | | |
| 72.0 to 72.5 | 37 | 1 | | | 1 | 1.00 |
| 72.5 to 73.0 | 42 | | | | | |
| 73.0 to 73.5 | 32 | | | | | |
| 73.5 to 74.0 | 41 | | | | | |
| 74.0 to 74.5 | 41 | 1 | | | 1 | .56 |
| 74.5 to 75.0 | 39 | | | | | |
| 75.0 to 75.5 | 29 | | | | | |
| 75.5 to 76.0 | 39 | | | | | |
| 76.0 to 76.5 | 34 | 1 | | | 1 | 4.70 |
| 76.5 to 77.0 | 42 | | | | | |
| 77.0 to 77.5 | 39 | | | | | |
| 77.5 to 78.0 | 45 | | | | | |
| 78.0 to 78.5 | 39 | 1 | | | 1 | .75 |
| 78.5 to 79.0 | 36 | | | | | |
| 79.0 to 79.5 | 22 | | | | | |
| **THIRD SESSION** | | | | | | |
| 128.0 to 128.5 | 49 | | | | | |
| 128.5 to 129.0 | 22 | | | | | |
| 129.0 to 129.5 | 23 | | | | | |
| 129.5 to 130.0 | 26 | | | | | |
| 130.0 to 130.5 | 36 | 1 | | | 1 | 1.00 |
| 130.5 to 131.0 | 27 | | | | | |
| 131.0 to 131.5 | 39 | | | | | |
| 131.5 to 132.0 | 34 | | | | | |
| 132.0 to 132.5 | 34 | 1 | | | 1 | .56 |
| 132.5 to 133.0 | 30 | | | | | |
| 133.0 to 133.5 | 24 | | | | | |
| 133.5 to 134.0 | 30 | | | | | |
| 134.0 to 134.5 | 36 | 1 | | | 1 | 1.00 |
| 134.5 to 135.0 | 35 | | | | | |
| 135.0 to 135.5 | 37 | | | | | |
| 135.5 to 136.0 | 33 | | | | | |
| 136.0 to 136.5 | 37 | 1 | | | 1 | .56 |
| 136.5 to 137.0 | 35 | | | | | |
| 137.0 to 137.5 | 33 | | | | | |
| 137.5 to 138.0 | 26 | | | | | |
| 138.0 to 138.5 | 31 | 1 | | | 1 | .75 |
| 138.5 to 139.0 | 23 | | | | | |
| 139.0 to 139.5 | 23 | | | | | |
| 139.5 to 140.0 | 34 | 1 | | | 1 | 3.75 |
| 140.0 to 140.5 | 21 | | | | | |
| 140.5 to 141.0 | 17 | | | | | |
| 141.0 to 141.5 | 27 | | | | | |
| 141.5 to 142.0 | 23 | | | | | |
| 142.0 to 142.5 | 25 | 1 | | | 1 | .75 |
| 142.5 to 143.0 | 25 | | | | | |

TABLE 9-III.—*Raw performance data for continuous-and discrete-avoidance tasks in MA-5 flight—Continued*

| Time from launch, min | Number of responses | | Number of shocks | | Discrete avoidance presentations | Duration of discrete avoidance reaction, sec |
|---|---|---|---|---|---|---|
| | Continuous avoidance lever | Discrete avoidance lever | Continuous avoidance | Discrete avoidance | | |
| | | | FOURTH SESSION | | | |
| 193.0 to 193.5 | 19 | | | | | |
| 193.5 to 194.0 | 11 | | | | | |
| 194.0 to 194.5 | 21 | | | | | |
| 194.5 to 195.0 | 17 | | | | | |
| 195.0 to 195.5 | 18 | 1 | | | 1 | 4.50 |
| 195.5 to 196.0 | 24 | | | | | |
| 196.0 to 196.5 | 22 | | | | | |
| 196.5 to 197.0 | 25 | | | | | |
| 197.0 to 197.5 | 31 | 1 | | | 1 | .56 |
| 197.5 to 198.0 | 22 | | | | | |
| 198.0 to 198.5 | 26 | | | | | |
| 198.5 to 199.0 | 24 | | | | | |
| 199.0 to 199.5 | 30 | 1 | | | 1 | .56 |
| 199.5 to 200.0 | 27 | | | | | |
| 200.0 to 200.5 | 22 | | | | | |
| 200.5 to 201.0 | 17 | | | | | |
| 201.0 to 201.5 | 24 | 0 | | 1 | 1 | 5.00+ |
| 201.5 to 202.0 | 24 | | | | | |
| 202.0 to 202.5 | 22 | | | | | |
| 202.5 to 203.0 | 23 | | | | | |
| 203.0 to 203.5 | 25 | 1 | | | 1 | .75 |
| 203.5 to 204.0 | 19 | | | | | |
| 204.0 to 204.5 | 18 | | | | | |
| 204.5 to 205.0 | 19 | | | | | |
| 205.0 to 205.5 | 20 | 1 | | | 1 | .75 |
| 205.5 to 206.0 | 18 | | | | | |
| 206.0 to 206.5 | 18 | | | | | |
| 206.5 to 207.0 | 18 | | | | | |
| 207.0 to 207.5 | 20 | 1 | | | 1 | 1.20 |
| 207.5 to 208.0 | 20 | | | | | |
| 208.0 to 208.5 | 19 | | | | | |
| 208.5 to 209.0 | 19 | | | | | |

TABLE 9–IV.—*Raw performance data for differential reinforcement of low rates in MA–5 flight*

| Interresponse time, sec | Number of reinforcements |
|---|---|
| First session, from T+21.5 min to T+31.5 min | |
| 20.3 | 0 |
| 33.3 | 1 |
| 33.0 | 1 |
| 36.3 | 1 |
| 26.4 | 1 |
| 35.0 | 1 |
| 55.4 | 1 |
| 51.6 | 1 |
| 25.7 | 1 |
| 29.7 | 1 |
| 28.2 | 1 |
| 89.1 | 1 |
| 37.2 | 1 |
| 27.1 | 1 |
| | 13 drinks |
| Second session, from T+85.5 min to T+95.5 min | |
| 39.0 | 1 |
| 29.0 | 1 |
| 37.0 | 1 |
| 27.8 | 1 |
| 25.4 | 1 |
| 28.0 | 1 |
| 69.9 | 1 |
| 27.3 | 1 |
| 35.7 | 1 |
| 24.6 | 1 |
| 29.3 | 1 |
| 21.5 | 1 |
| 34.4 | 1 |
| 26.2 | 1 |
| 86.8 | 1 |
| 37.5 | 1 |
| | 16 drinks |

TABLE 9–IV.—*Raw performance data for differential reinforcement of low rates in MA–5 flight—Concluded*

| Interresponse time, sec | Number of reinforcements |
|---|---|
| Third session, from T+149.5 min to T+159.5 min | |
| 56.0 | 1 |
| 23.8 | 1 |
| 25.0 | 1 |
| 29.5 | 1 |
| 30.6 | 1 |
| 13.2 | 0 |
| 51.2 | 1 |
| 29.3 | 1 |
| 18.0 | 0 |
| 22.2 | 1 |
| 23.4 | 1 |
| 22.6 | 1 |
| 23.6 | 1 |
| 26.9 | 1 |
| 26.2 | 1 |
| 23.8 | 1 |
| 21.1 | 1 |
| 27.7 | 1 |
| 28.1 | 1 |
| 70.7 | 1 |
| | 18 drinks |

On the FR task, the subject received 13 pellets during the first FR session. He exhibited an extremely stable response rate which, as can be seen in figure 9–6, closely approximated his preflight average. A count of the number of food pellets remaining in the feeder following the flight verified that it was functioning and supported the data which indicated that the subject received 13 pellets in session 1, and 4 in the unrecorded session 2. The raw performance data for this session are presented in table 9–V. While the second session of the FR task was in effect a malfunction occurred in the switch of center lever; and although it presented no major problem during

TABLE 9–V.—*Raw performance data for fixed ratio task in MA–5 flight*

[First session, from T+37.5 min to T+48.25 min]

| Number of responses on center lever | Number of pellets dispensed | Number of responses per second |
|---|---|---|
| 16 | 1 | 3.2 |
| 23 | 1 | 3.0 |
| 47 | 1 | 3.0 |
| 22 | 1 | 4.6 |
| 47 | 1 | 3.1 |
| 46 | 1 | 3.0 |
| 48 | 1 | 2.8 |
| 47 | 1 | 3.5 |
| 48 | 1 | 3.1 |
| 51 | 1 | 3.0 |
| 35 | 1 | 3.0 |
| 48 | 1 | 3.3 |
| 46 | 1 | 3.0 |
| | 13 | |

the FR task, the malfunction prohibited an accurate measurement of performance on sessions 2 and 3 of the FR task as well as the performance on the two subsequent oddity components. Figure 9–5 shows the performance of the animal after 30 minutes of weightless flight while the center lever switch was still functioning. The chimpanzee's steady uninterrupted actuation rate is responsible for the consistency of the slope.

Figure 9–6 also shows the animal's performance of the oddity task in relation to the others. A detailed account of performance on the first session of the oddity problems is presented in table 9–VI. During this session the subject performed at 64.2-percent efficiency which was essentially the same as his preflight mean of 66 percent. He received 10 shocks due to errors in discrimination. As a result of the malfunctioning center lever, the efficiency of discrimination is virtually meaningless for sessions 2 and 3; however, certain inferences can be made concerning the behavior during these periods.

As shown in table 9–VII in which performance on the second session of the oddity problems is presented, the first problem required a response on the center lever. On the basis of previous performance, it can be inferred that the subject would make this discrimination correctly two out of three times (66 percent). Yet, because of the lever malfunction, a response on the center lever was not effective in turning off the displays. Consequently, the subject

TABLE 9–VI.—*Performance of the oddity problem for session 1*

[Efficiency=18/28=64.2 percent]

| Problem no. | Response by lever | | | Number of shocks |
|---|---|---|---|---|
| | Lever 1 | Lever 2 | Lever 3 | |
| 1 | X | □ | | ✓ |
| 1 | | ⊠ | | |
| 2 | | | ⊠ | |
| 3 | | X | □ | ✓ |
| 3 | | | ⊠ | |
| 4 | ⊠ | | | |
| 5 | | ⊠ | | |
| 6 | X | | □ | ✓ |
| 6 | | X | □ | ✓ |
| 6 | X | | □ | ✓ |
| 6 | X | | □ | ✓ |
| 6 | | | ⊠ | |
| 7 | ⊠ | | | |
| 8 | □ | X | | ✓ |
| 8 | □ | X | | ✓ |
| 8 | ⊠ | | | |
| 9 | | | ⊠ | |
| 10 | | ⊠ | | |
| 11 | ⊠ | | | |
| 12 | | □ | X | ✓ |
| 12 | | ⊠ | | |
| 13 | | X | □ | ✓ |
| 13 | | | ⊠ | |
| 14 | ⊠ | | | |
| 15 | | ⊠ | | |
| 16 | ⊠ | | | |
| 17 | | ⊠ | | |
| 18 | | | ⊠ | |
| Total | 10 | 11 | 7 | 10 |

X=Response. □=Required response. ⊠=Correct response.

was still confronted with the problem; and with the time rapidly approaching in which a shock would be delivered for "nonresponse," the subject pressed the left lever which turned off the displays, but since the action was incorrect, it also resulted in a shock. As a result, the "insoluble" problem was presented again and if the probability of correct solution can be inferred as before, the subject made a correct response—the pressing of the center lever. However, the result was the same as for the first presentation of the problem; namely, the displays remained on. Since the subject had experienced an identical situation on the first presentation of the problem, and since he had received a shock for pressing the left lever, it may be inferred that he varied his behavior and responded on the right lever. Moreover, the alternation of responses between the left and right levers was

TABLE 9–VII.—*Performance of the oddity problem for session 2*

| Problem No. | Response by lever | | | Number of shocks |
|---|---|---|---|---|
| | Lever 1 | Lever 2 | Lever 3 | |
| 1 | | □ | X | ✓ |
| 1 | X | □ | | ✓ |
| 1 | | □ | X | ✓ |
| 1 | | □ | X | ✓ |
| 1 | X | □ | | ✓ |
| 1 | | □ | X | ✓ |
| 1 | X | □ | | ✓ |
| 1 | | □ | X | ✓ |
| 1 | X | □ | | ✓ |
| 1 | | □ | X | ✓ |
| 1 | X | □ | | ✓ |
| 1 | | □ | X | ✓ |
| 1 | X | □ | | ✓ |
| 1 | | □ | X | ✓ |
| 1 | X | □ | | ✓ |
| 1 | | □ | X | ✓ |
| 1 | X | □ | | ✓ |
| 1 | | □ | X | ✓ |
| 1 | | □ | X | ✓ |
| 1 | | □ | X | ✓ |
| 1 | X | □ | | ✓ |
| 1 | | □ | X | ✓ |
| 1 | X | □ | | ✓ |
| 1 | | □ | X | ✓ |
| 1 | X | □ | | ✓ |
| 1 | | □ | X | ✓ |
| 1 | | □ | X | ✓ |
| 1 | | □ | X | ✓ |
| 1 | X | □ | | ✓ |
| 1 | | □ | X | ✓ |
| 1 | | ⊠ | | |
| 2 | | | ⊠ | |
| 3 | | | ⊠ | |
| 4 | ⊠ | | | |
| 5 | | □ | X | ✓ |
| 5 | X | □ | | ✓ |
| Total | 15 | 1 | 23 | 35 |

X = Response. □ = Required response. ⊠ = Correct response

apparent on subsequent presentations of the problem. Eventually, however, on the 34th presentation of the first problem, the switch functioned properly and the problem was solved, lending credence to the hypothesis that the subject was making the correct discrimination on two out of every three presentations of the problem before varying his behavior. The fact that more responses were made during this session on the right lever than on the left lever is also significant as is the finding that during the third session the subject, while also exhibiting the alternation behavior, made 10 responses on the left lever and 33 responses on the right lever in attempting to solve the first problem, the only one presented during the session. This behavior is explained on the basis of the number of possible reinforcements for the CA and DA tasks since for the CA task (right lever) at least one response is required every 20 seconds to avoid six shocks; whereas only one response every 2 minutes is required on the left lever to avoid shock for the DA task.

An indication of the subject's discriminatory ability can be derived from the fact that no lever presses were recorded during the nine 6-minute rest periods.

## Results and Discussions

The ballistic flight and subsequent tests led to the conclusion that the major environmental factors affecting performance were the forces acting upon the subject during launch and reentry.

During both the ballistic and the orbital flights each of the subjects was performing the CA–DA tasks during the launch and reentry periods. Concerning the chimpanzee's performance of the CA task, the variability in response rate following launch was expected on the basis of exposure to simulated launch accelerations on the centrifuge. On the MR–2 flight, there was a sharp decline in rate, and immediately following launch, the subject received his first shock; however, it is believed that this shock was due to a malfunction in the timing apparatus since careful examination of the telemetry recording shows that the time between responses at this period of the flight was less than 15 seconds. This decrement was not observed in the MA–5 flight. It is possible that the reduction in response rate of the subject during the reentry period of the MR–2 flight was a function of the 17g experienced during the launch as compared with the two smaller accelerations (6.8g and 7.6g) for MA–5. However, in the MA–5 flight the performance immediately following launch was more variable than performance during this period of the MR–2 flight, and it was during this time that the

subject received his first shock. Performance was not affected during the weightless portion of either flight.

During the reentry period of the MR–2 flight, a gradual decrement in the response rate was observed. There was no decrement in the MA–5 flight. This finding, as was true of the performance following launch, could be attributed to the differences in the magnitude of the accelerations experienced by the two subjects. During the MR–2 flight the animal was subjected to 14g for 5 seconds and 10g for 10 seconds during reentry; whereas a deceleration of only 7.8g was experienced during the orbital reentry. It may be that launch and reentry accelerations of the magnitude and duration of the MR–2 flight affected subsequent performance rate of the CA task. However, this statement is not without qualification. While it is true that a reduction in rate occurred, the number of responses for any 20-second period was never more than two standard deviations from the preflight mean. This fact becomes more striking in MA–5 flight. Here, performance of the CA task was essentially the same as during the preflight with very little variability.

An increase in the variance on the performance of the DA task was observed in the MA–5 flight. This increase did not occur in the ballistic flight. The subject received one shock for failing to respond to the fourth presentation of the blue light on the fourth DA session. However, in comparing the preflight with the inflight means, it was concluded that the visual monitoring or reaction time was unaffected.

The performance of the DRL task was also unaffected. In this regard, note that the malfunctioning of the center lever, which resulted in the subject receiving 35 shocks on the second session of the oddity problem, did not disrupt his subsequent performance on either the third DRL session or the third session of the CA–DA components. And likewise, the 41 shocks received during the third oddity session did not affect performance during the subsequent fourth session of the CA–DA tasks. Certainly, following a malfunction of this nature, it might be expected that behavior would be disrupted, but this was not in evidence.

Performance of the first FR session was extremely stable and the discrimination accuracy for the first oddity session was also close to the preflight mean. Unfortunately, the malfunctioning of the center lever made the measurement during the two subsequent sessions on both tasks meaningless.

In general, from a behavioral standpoint it can be concluded that, with the exception of the difficulty encountered with the middle lever, the flight was successful. The tasks selected proved to be adequate, but more important, the telemetry afforded continuous recording of the behavioral data. The MA–5 flight also provided the weightless environment necessary for testing both the pellet feeder and the water dispenser; neither of these showed any evidence of malfunction.

## Conclusions

A chimpanzee was trained to perform a complex multiple operant task during the second animal flight in the Project Mercury program in which a spacecraft orbited the earth twice. As a result of this flight, it was concluded that:

1. Behavioral measurements should be made together with the usual physiological measurements if the status of an animal subject is to be fully appraised.
2. The noise and vibration accompanying launch did not affect performance.
3. Accelerations accompanying launch and reentry in excess of 7g had an immediate effect upon performance; however, recovery to a prelaunch level was rapid.
4. Performance decrements did not occur during weightlessness.
5. Adaptation to weightlessness took place during a 3-hour exposure.
6. Performance was maintained during the launch and reentry acceleration.
7. Eating and drinking can be accomplished during weightlessness.
8. The visual and temporal response processes and the continuous and discrete motor behavior were unaffected by the weightless state.
9. The pellet and water dispensers functioned excellently during weightlessness.
10. Despite serious distractions, young chimpanzees have served as highly reliable subjects in space flights.

## References


1. Reynolds, Herbert H., Grunzke, Marvin E., and Rohles, Frederick H., Jr.: The Effects of Simulated Launch and Reentry Profiles on Chimpanzee Performance. Air Force Missile Development Center TDR–62–1, Mar. 1962.
2. Rohles, Frederick H., Jr., Reynolds, Herbert H., Grunzke, Marvin E., and Farrer, Donald N.: A Laboratory Model for a Fourteen Day Orbital Flight with a Chimpanzee. Air Force Missile Development Center TR–61–33, Oct. 1961.

3. Grunzke, M. E.: A Liquid Dispenser for Primates. Jour. Exp. Analysis of Behavior, vol. 4, 1961, p. 326.
4. Grunzke, Marvin E.: Feeding Devices for Use With Primates in Space Flight. Air Force Missile Development Center TDR-61-35, Dec. 1961.
5. Belleville, Richard E., Rohles, Frederick H., Jr., and Grunzke, Marvin E.: Behavior of the Chimpanzee on a Complex Multiple Schedule. Air Force Missile Development Center TR-61-27, Aug. 1961.

# 10. MEDICAL AND PHYSIOLOGICAL ASPECTS *of the* MA–5 FLIGHT

By William E. Ward*

The chimpanzee subject, No. 81, was purchased by the U.S. Air Force on April 3, 1960. From this time until November 27, 1961, it was subjected to six complete quarterly physicals and many other examinations in the course of various studies. All of the findings of these examinations including the blood-pressure observations, which were frequently elevated above the normal values of resting, relaxed humans, were within normal ranges for immature chimpanzees exposed to similar conditions of examinations under restraint. More comprehensive information on the blood pressure is presented in section 11.

In addition to extensive behavioral training, the subject was exposed to four data acquisition flights and two simulated Mercury-Atlas acceleration profile tests on the centrifuge at the University of Southern California (ref. 1).

The restraint system and physiological sensors were the same as those used during the MR–2 flight with the following three exceptions: All ECG electrodes were of the steel suture type, venous and arterial catheters were inserted for blood pressure measurements, and the subject was catheterized for collection of urine during the flight. Flight data were recorded continuously on the onboard tape (fig. 10–1) and telemetered to ground stations.

## Results

Physiological data from the MA–5 flight are presented in figure 10–2. Total flight time from lift-off to landing was 3 hours 20 minutes 59 seconds. Data were recorded continuously from launch until 10 minutes after landing, and the flight data values include the postlanding period.

For the period 5 hours prior to launch, the mean heart rate was 94 beats per minute. During this time, the subject was lying quietly in the couch. The minimum heart rate was 82 beats per minute; maximum was 128 beats per minute (fig. 10–3).

At T−2 minutes, the behavior program was turned on. Heart rate rose from 86 beats to 111 beats per minute at 1 minute before lift-off. At peak acceleration in the first stage at approximately T+2 minutes, the heart rate was 130 beats per minute (fig. 10–2). During the first orbital pass, heart rate was labile, ranging from 102 to a momentary 153 beats per minute. The lowest rate recorded during flight was 100 beats per minute. Maximum rate was a momentary 180 beats per minute which occurred during reentry at approximately T+3 hours 13 minutes. Mean pulse rate during flight was 128 beats per minute.

Minimum momentary respiration rate recorded before the launch was 9 and the maximum was 28 breaths per minute. The mean respiration rate during the preflight period was 14 breaths per minute. With launch, the rate rose from a mean of 14 to approximately 30 inspirations per minute at T+5 minutes. It fluctuated during the flight from a minimum rate of 14 to a maximum of approximately 80 breaths per minute at 3 hours 13 minutes which was during peak acceleration of reentry. Mean respiration rate during the flight was 28 breaths per minute.

Eight hours prior to flight, the subject's rectal temperature was 99.4° F. Temperature dropped to approximately 96° F during the pre-flight countdown. At lift-off the temperature was 96.2° F. There was a gradual rise during the first orbital pass to 97.5° F. During the first 20 minutes of the second orbit, the temperature rose 1°. At 2 hours 50 minutes, the subject's temperature was 99.9° F. Ten minutes after landing, the rectal temperature was 100.1° F.

A number of premature ventricular contractions (PVC) occurred during the flight (fig. 10–1). The

*Captain, U.S. Air Force.

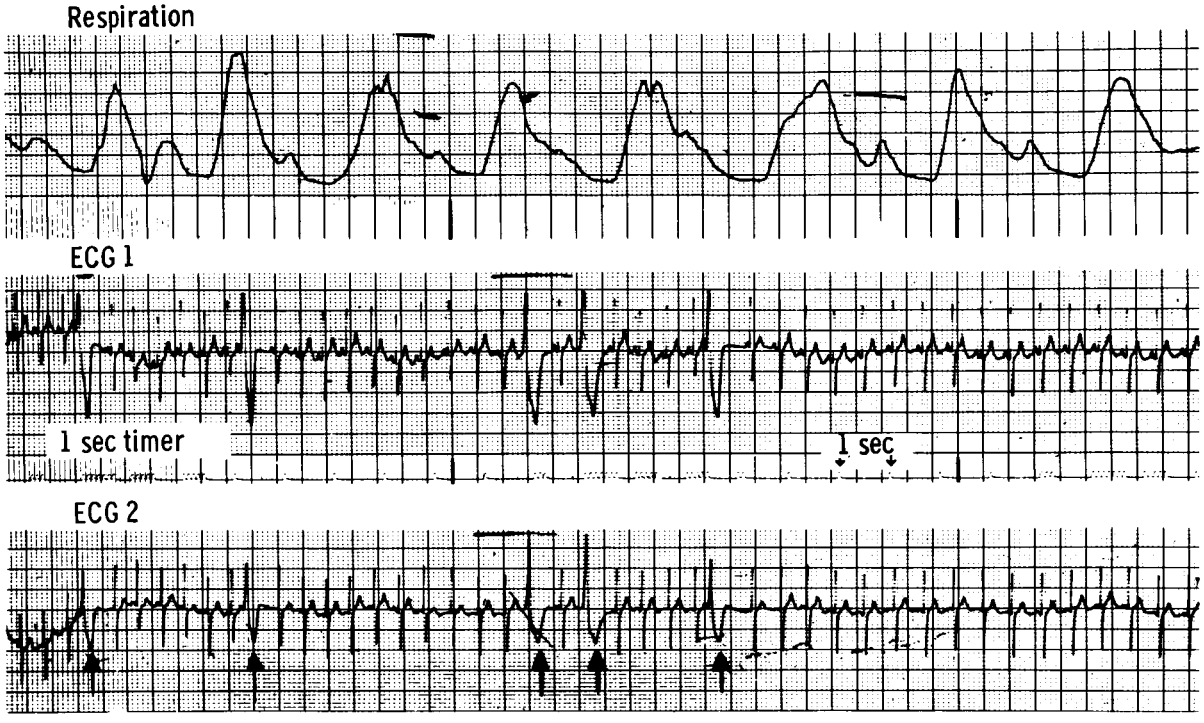



FIGURE 10–1.—Record from a monitoring station at T+94 minutes showing premature ventricular contractions (arrows). The respiratory record is shown above the two electrocardiograph leads.

first occurrence was 30 minutes after lift-off and was reported from Zanzibar. The irregularities were present throughout the flight. The PVC's are discussed in detail in section 12.

The subject did not land in the primary recovery area, and as a result the spacecraft was not picked up by the U.S.S. *Stormes* until 1 hour and 20 minutes after landing. There was a delay of 3 hours and 20 minutes in removing the subject from the spacecraft and couch. A cursory examination of the subject at this time resulted in the following findings: Rectal temperature, 102° F; respiration rate, 38 breaths per minute; blood pressure, 130/90 mm Hg; heart rate, 74 beats per minute. In addition, the subject had broken through the protective belly panel and had removed or damaged most of the physiological sensors. He had also forcibly removed the urinary catheter while the balloon was still inflated.

The subject was removed from the U.S.S. *Stormes* at approximately 7:00 a.m. e.s.t. on November 30, 1961, and taken to the Air Force hospital in Bermuda for examination. The findings were as follows: Rectal temperature, 97.6°F; respiration rate, 16 breaths per minute; blood pressure, 128/80 mm Hg; heart rate, 100 beats per minute. The subject weighed 39.5 pounds. Complete blood count and urinalysis indicated a bacterial infection of the bladder. ECG leads 1, 2, 3, and 2VR, 2VL, 2VF, and $V_1$, $V_3$, $V_5$ revealed no abnormal conduction patterns. The subject appeared to be fatigued but alert; the penis was slightly edematous, as a result of the forcible extraction of the catheter. Body X-rays indicated no abnormalities.

## Discussion

Figure 10–2 is a composite plot of flight physiology from the subject and values obtained from the subject and four other chimpanzees during two series of centrifuge experiments prior to the flight. These experiments were conducted at the University of Southern California in September 1961, in order to determine the effects upon performance and physiological measures of the exposure of chimpanzee subjects to the lift-off and reentry accelerations anticipated during the MA–5 flight. (See ref. 1.) During the first 10 minutes of actual flight, the subject's heart and respiration rates and rectal temperature were lower than those recorded for the centrifuge tests.

During orbital flight, respiration rate remained below the centrifuge test values, but heart rate

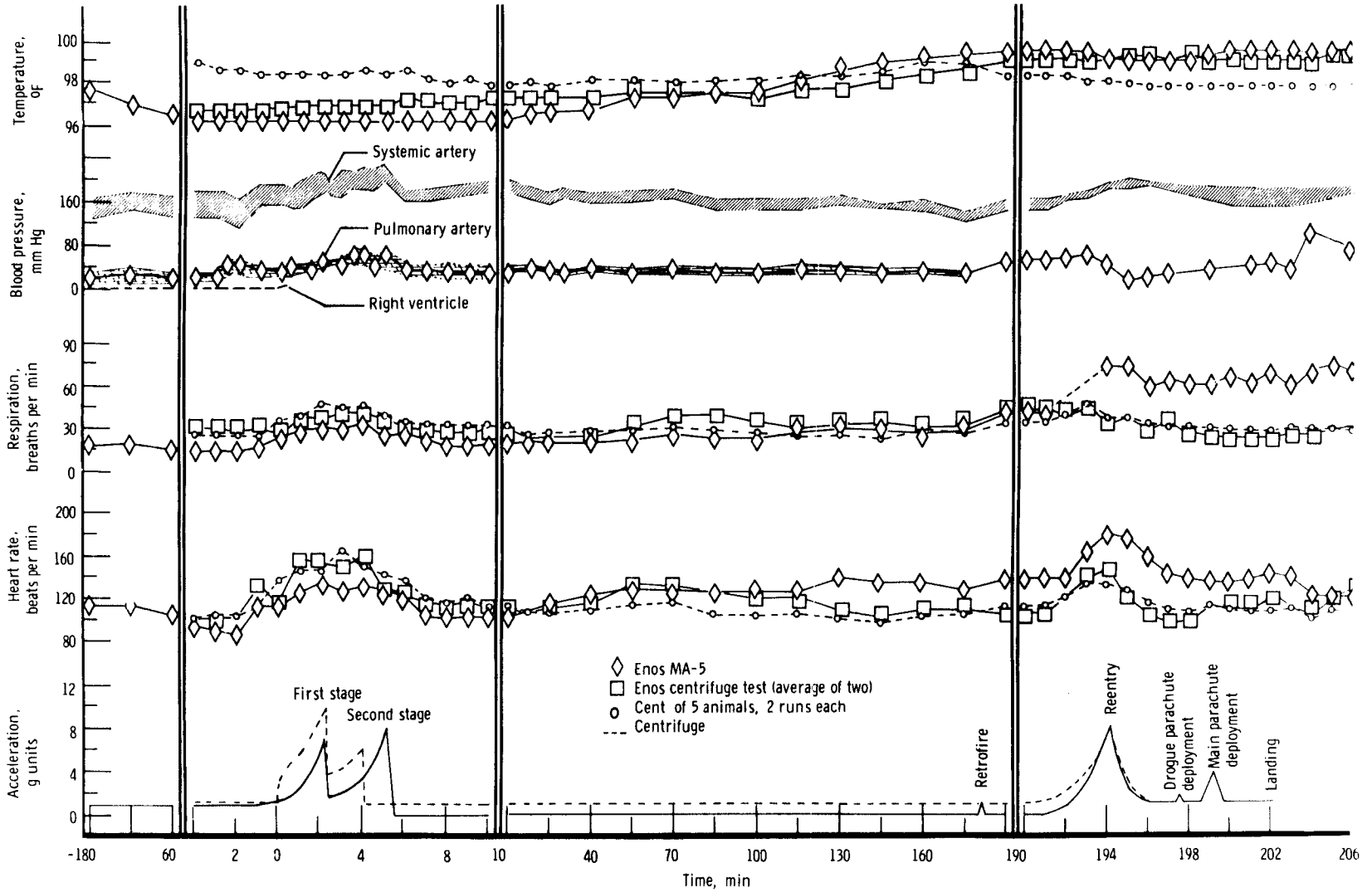



FIGURE 10-2.—Composite diagram of acceleration, heart rate, respiration rate, blood pressure, and temperature. The respiration rate only deviates from control during the reentry period when there is a good deal of oscillation on the parachute. The diamonds represent blood-pressure data as recorded by the galvanometer of low sensitivity. Some right-ventricular data were available for the first few minutes and then changed to pure pulmonary arterial pressure data as the catheter ceased altering position and stayed in the pulmonary artery. Above pulmonary arterial pressure is systemic arterial pressure. The pulse pressure is indicated by the shading. There is a return of systemic arterial pressure toward preflight control levels during the weightless period. Note that the pressure remained elevated throughout a 3-hour period of preflight observation. During the 1g and 0g phases of flight, arterial systoles exceeding 160 mm Hg were estimated from the slope of the wave.

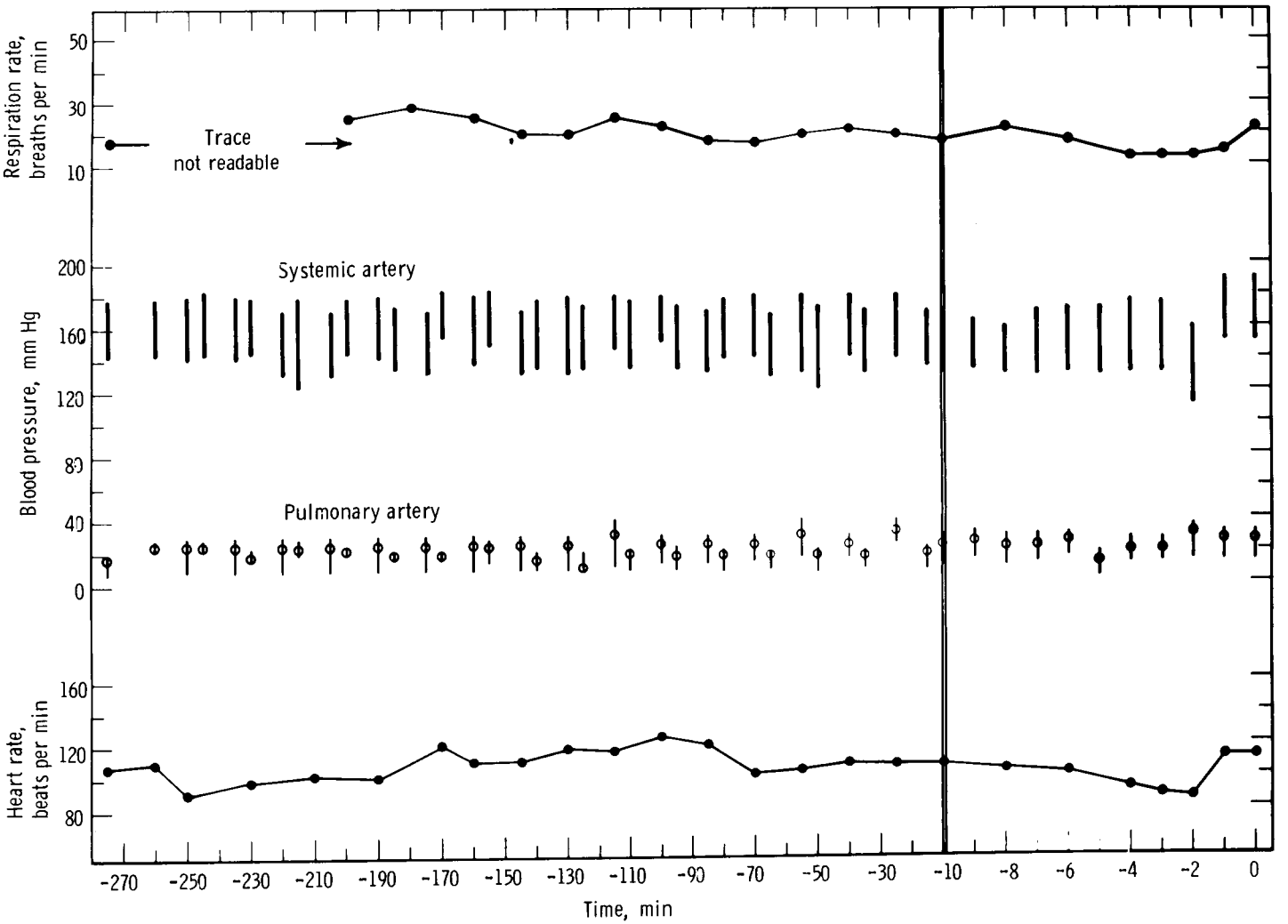



FIGURE 10-3.—Records of physiological parameters during 4½ hours of the launch-pad countdown time for the MA-5 subject. The first trace represents heart rate in beats per minute; second, pulmonary artery pressure. The circles indicate the pressure as measured with a galvanometer of low sensitivity. Vertical lines connect pulmonary arterial systolic and diastolic pressure as measured by a sensitive galvanometer. Systemic artery pressure is also registered by vertical lines connecting systole and diastole. Top line represents respiration per minute. All points on the graph are based on arithmetic means of all events for each minute.

increased. During the acceleration of reentry, heart and respiration rates rose well above those recorded during the centrifuge runs. Means and standard deviations of heart and respiration rates for preflight and flight periods are presented in the following table:

| | *Preflight* | *Flight* |
|---|---|---|
| Heart rate: | | |
| Mean, beats per minute.... | 94 | 128 |
| Standard deviation, beats per minute..... | 8 | 15 |
| Respiration: | | |
| Mean, breaths per minute.. | 14 | 28 |
| Standard deviation, breaths per minute..... | 2 | 15 |

The subject's heart and respiration rates were significantly increased during the flight but did not exceed control mean values established during an earlier ground test series. (See ref. 2.)

Probably the most significant change seen in the MA–5 flight subject was in the postflight hematological values. The differential white blood count showed a reversal of the neutrophile-lymphocyte ratio as after the MR–2 flight (table 10–I). Changes of this type, although not as severe, have been observed in subject exposed to other similar stressful conditions, as reported in references 2 and 3. The increase in white blood count may be attributed to a urinary infection as a result of trauma following the forcible removal of the catheter by the subject during the postflight period. All other findings were within normal ranges.

## Concluding Remarks

During the MA–5 flight, heart and respiration rates of the chimpanzee subject increased significantly from prelaunch values, but did not exceed control mean values established for restrained chimpanzees. A 2° F rise in rectal temperature which occurred during flight and landing was not considered significant. Preliminary hematological findings indicate that the total flight and recovery situation including forcible removal of the catheter was stressful to the subject. The urinary infection which occurred immediately postflight complicated complete interpretation of hematological data.

## References


1. Cook, James E., Fineg, Jerry, and Miksch, Eldon D.: Physiological Base-Line Studies of Zoological Specimens. Phase I: Hematological Values of Immature Chimpanzees. Air Force Missile Development Center TN–60–9, July 1960.
2. Archibald, Erwin R., and Ward, William E.: Chimpanzee Temperature-Humidity Tolerance Tests—Control Tests at 80° F, 50 Percent Relative Humidity. Air Force Missile Development Center TR–61–11, Apr. 1961.
3. Fineg, Jerry, Britz, William E., Jr., et al.: Physiological Base-Line Studies of Zoological Specimens—Clinical Observations and Methods Used in the Treatment of Young Chimpanzees. Air Force Missile Development Center TR–61–12, Apr. 1961.

TABLE 10–I.—*Preflight and postflight physical examination of MA–5 subject*

| | Preflight examination T—24 hr | T—7 hr | Postrecovery examination, Bermuda on Nov. 30, 1961, at 9:00 a.m. e.s.t. | Cape Canaveral Dec. 1, 1961, 9:00 a.m. e.s.t. | Dec. 4, 1961 | Dec. 7, 1961 | Dec. 19, 1961 | Jan. 18, 1962 |
|---|---|---|---|---|---|---|---|---|
| Age, months | 63 | 63 | 63 | 64 | | | | |
| Weight, lb | 38.5 | 39.5 | 39.5 | 41 | | | | |
| Rectal temperature, °F | 97.8 | 95.6 | 97.6 | 98 | | | | |
| Blood pressure, mm Hg | 112/76 | 140/100 | 128/80 | 130/98 | | | | |
| Heart rate, beats per min | 92 | 88 | 100 | 112 | | | | |
| Respiration, breaths per min | 20 | 16 | 16 | 20 | | | | |
| ECG | All leads normal. | All leads normal. | All leads normal. | All leads normal. | | | | |
| Complete blood count: | | | | | | | | |
| White blood cells (200 cell count) | 9,500 | | 35,000 | 14,550 | 10, 950 | 19, 000 | 11, 650 | 12, 550 |
| Neutrophiles, percent | 64 | | 66 | 51 | 38 | 45 | 30 | 21 |
| Myelocytes, percent | 4 | | | 3 | | | 4 | 2 |
| Lymphocytes, percent | 20 | | 29 | 43 | 59 | 50 | 57 | 38 |
| Monocytes, percent | 4 | | | | [a] 1 | 3 | [a] 1 | [a] 1 |
| Eosinophiles, percent | 5 | | 4 | | | | 2 | 38 |
| Sed. rate, mm | 28 | | 15 | 38 | 16 | 26 | 14 | 24 |
| Red blood cells, millions per $mm^3$ | 4.93 | | 4.88 | 4.38 | 4.39 | 4.37 | 5.45 | 5 |
| Hematocrit, percent | 45 | | 46 | 44 | 43 | 33 | 39 | 41 |

[a] June 1961.

# 11. BLOOD PRESSURE INSTRUMENTATION *for the* MA–5 FLIGHT

By John P. Meehan, M.D.,*
Jerry Fineg,** and
Charles D. Wheelwright***

In an effort to record arterial and venous pressures for the MA–5 chimpanzee orbital flight, and because time was a critical factor in the selection and development of instrumentation, it was decided to adapt standard techniques previously used for cardiovascular measurement in rocket flights. (See ref. 1.)

Since the overriding requirements were those of high reliability and safety to the chimpanzee subject, a system of sensing the pressures based on arterial and venous catheterization with very small tubing was employed.

Recording of the data was accomplished by means of a galvanometer oscillograph designed to use 16 mm motion picture film. The pressure sensing and recording system originally was required to be operable independent of external power source. This latter requirement was changed and the recording system was operated on electrical power provided in the MA–5 spacecraft. The pressure recording effort was designed to be done on a noninterference basis and whether it was used or not would not affect the overall mission.

## Instrumentation

The pressure sensor system was mounted in the spacecraft between the leg restraint troughs of the MA–5 chimpanzee couch (figs. 2–2, 3–2, 11–1, and 11–2). The arterial pressure was measured by means of a Statham Model PM131TC transducer with a range of $\pm 12.5$ psi. A similar transducer, with a range of $\pm 2.5$ psi, was used for venous pressures. The pressure gauges were mounted in a lucite block that was machined to contain two cylinders, one for each gauge. Fittings were provided at one end of the cylinders for PE 50 polyethylene tubing. The cylinders were fitted with pistons which were driven by means of a small motor. Each gauge, then, had free communications to one cylinder and to one fitting for the polyethylene tubing (fig. 11–3). The cylinders were filled with dilute heparin solution (1 cc of 1,000 units/cc heparin in 50 cc saline). The motor drive to the pistons was such that the heparin solution could be perfused through each of the pressure sensing systems at a rate of approximately 2.5 ml/hour. A total of 20 continuous hours of operation was possible with the pressure sensing apparatus.

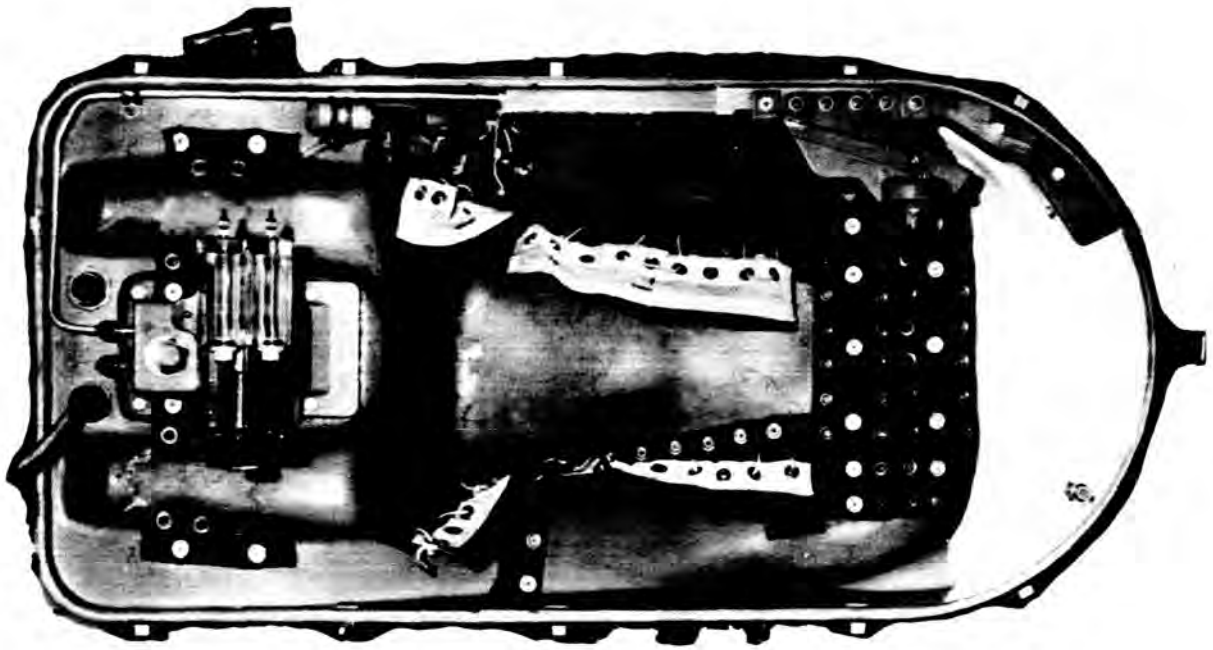
The electrical outputs of the pressure transducers were recorded by means of a specially designed galvanometer oscillograph (figs. 11–4 and 11–5). The oscillograph used 16 mm film moving at 5.7 inches per minute with a capacity of 500 feet. This recorder permitted continuous operation for more than 16 hours. The recorder itself was designed to be both water and gas tight and would operate when completely submerged.

The total power consumption for the transducer unit and recorder was 0.8 ampere at 6.0 volts. Calibration of the system was manometric and was conducted just prior to flight time.

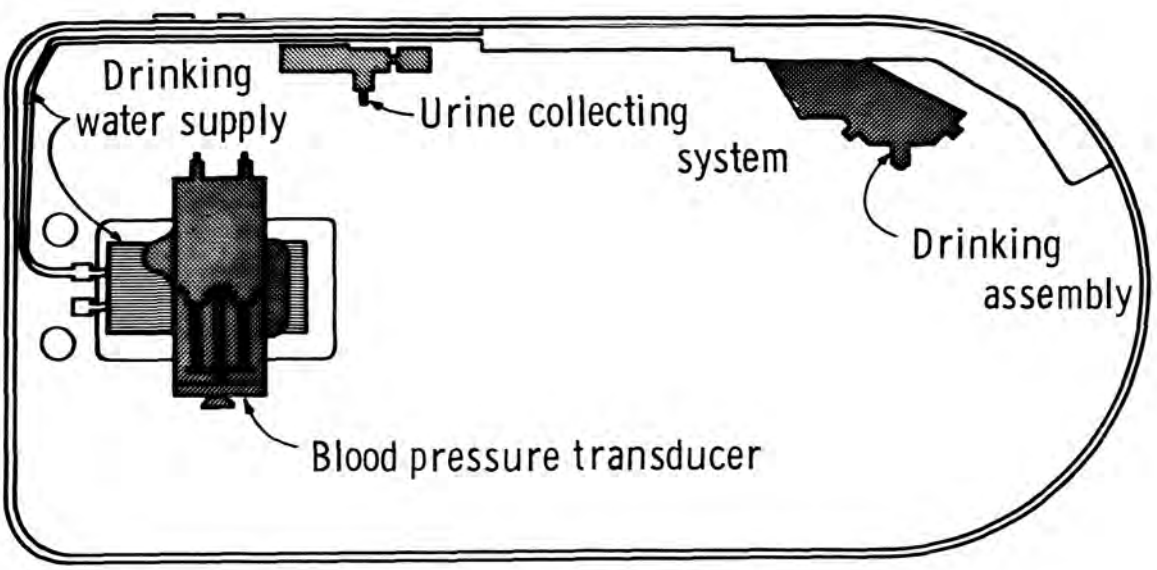
## Methods

The anterior tibial artery of the chimpanzee subject was used for obtaining the arterial pressure. A length of 26 gauge, stainless steel wire was introduced into the vessel through a No. 21 thin-wall needle. The needle was then removed and fine PE 50 poly-

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(a) Photographs




(b) Schematic diagram.

FIGURE 11-1.—Orbital couch showing the blood pressure sensor system mounted on top of the triangular water tank sector between the leg troughs.

ethylene tubing whose diameter is approximately 1 mm with fitting, was slipped over the wire and advanced a few inches into the vessel. The wire was removed and the polyethylene tubing was suitably connected to the pressure sensing system.

The saphenous vein was used for the venous pressure. PE 50 tubing containing an appropriate length of 26 gauge stainless steel wire was introduced through a No. 18 thin-wall needle and advanced a distance considered sufficient to reach the inferior vena cava just below the diaphragm. The needle was then removed by threading backwards along the tube and the gauge fitting was then attached to the tube and connection established with the gauge. As demonstrated by the onboard pressure recordings recovered after the flight, the tip of the catheter came to lie in

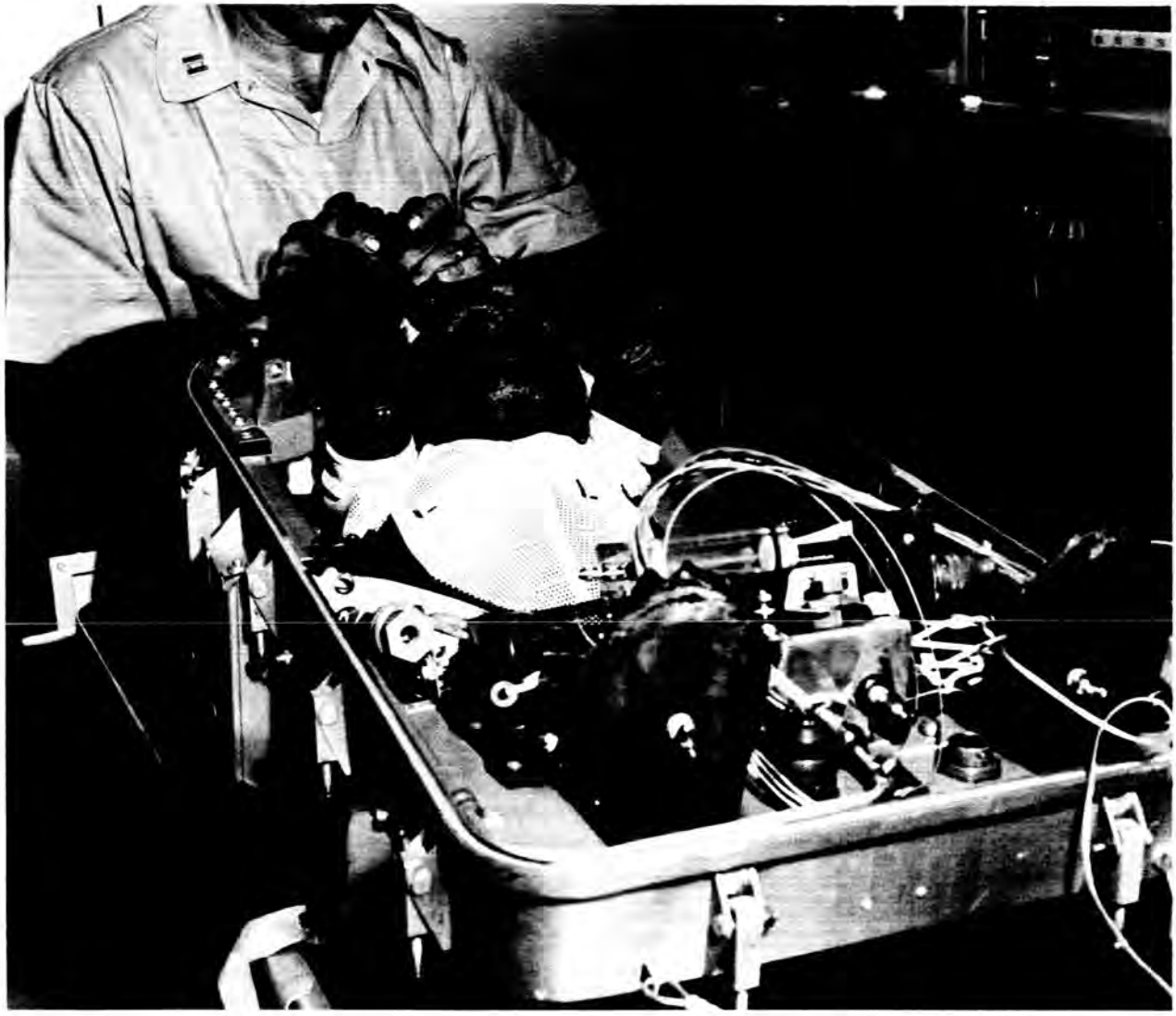
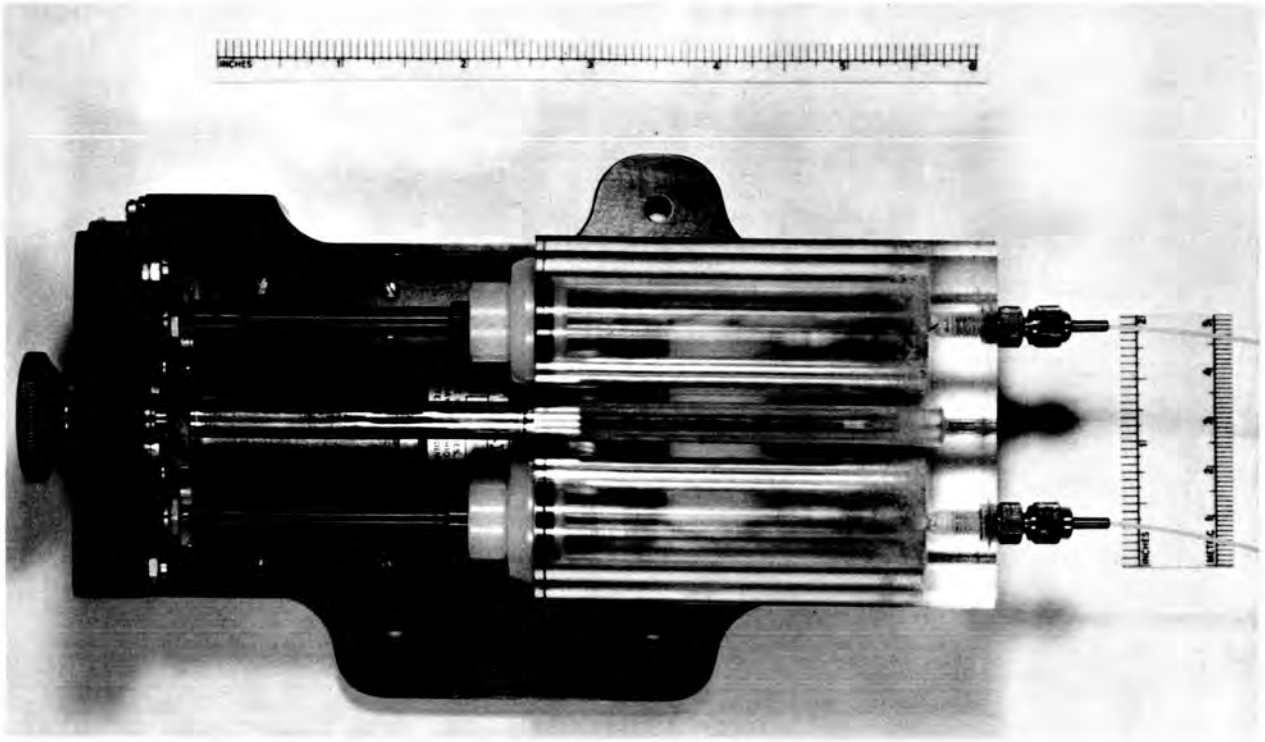


FIGURE 11–2.—View of the animal in the couch. The electrode attachment to the soles of the feet is visible. Between the legs is the water reward reservoir on top of which are mounted the syringes infusing the anticoagulant and the two pressure gages. The fine tubing leading to the vessels can be seen running in two loops from the fittings on the syringes toward the feet.

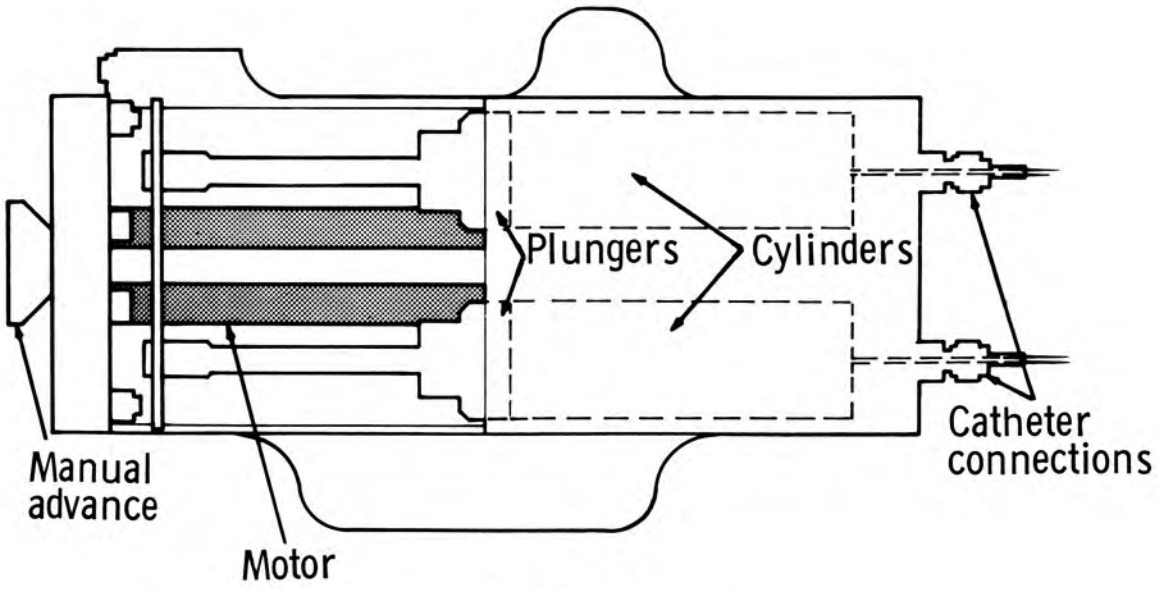
the right ventricle in such a position that it could move easily between the right ventricle and the pulmonary artery. The fact was not ascertained with certainty until the onboard pressure records became available for study.

## Results

The vascular pressures were recorded from 288 minutes before lift-off to 10 minutes after landing. During the rest period on the launch pad, arterial pressures ranged from 168/133 mm Hg to 183/143 mm Hg (fig. 11–6). (Pressures over 160 mm Hg were estimated from the slope of the wave.) The subject's arterial pressures were responsive to events occurring outside the chimpanzee couch and showed variations when, for example, the Mercury spacecraft had to be reentered prior to lift-off. Pulmonary artery pressures ranged from 24/14 to 27/19 mm Hg. The ventricular diastolic pressure was 0 mm Hg. (See fig. 11–6.) During orbit, the mean systemic artery pressure approximated 150 mm Hg and ranged from a maximum of 200 mm Hg systolic to a minimum of 120 mm Hg diastolic while mean pulmonary artery pressure held constant at approximately 25 mm Hg. Because the peaks were not recorded on the film, all systemic arterial pressures over 160 mm Hg were

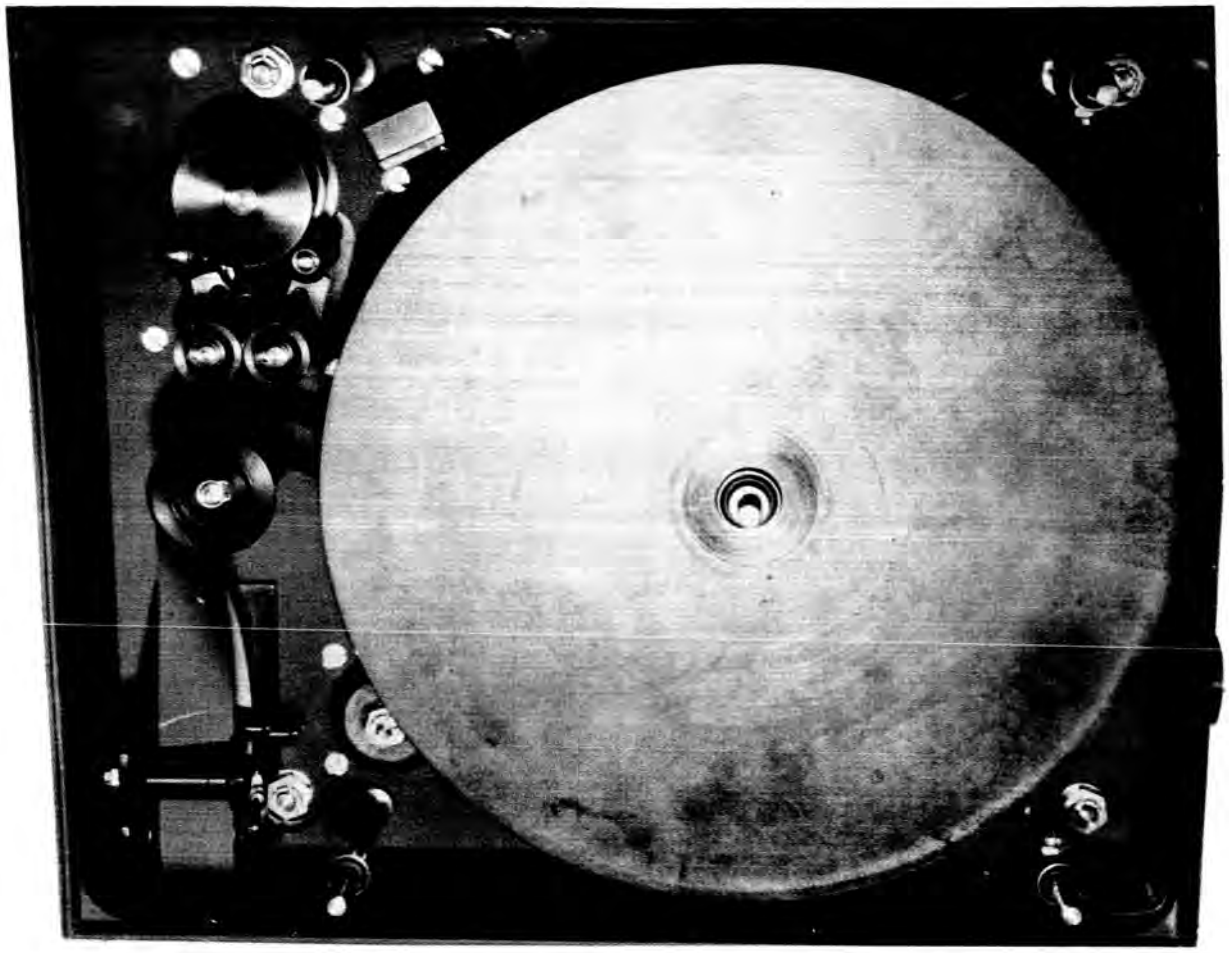


(a) Photograph.




(b) Schematic diagram.

FIGURE 11-3.—Blood pressure system. The pressure sensor consists of two heparin filled syringes driven by a geared-down motor so slowly that emptying required over 16 hours.



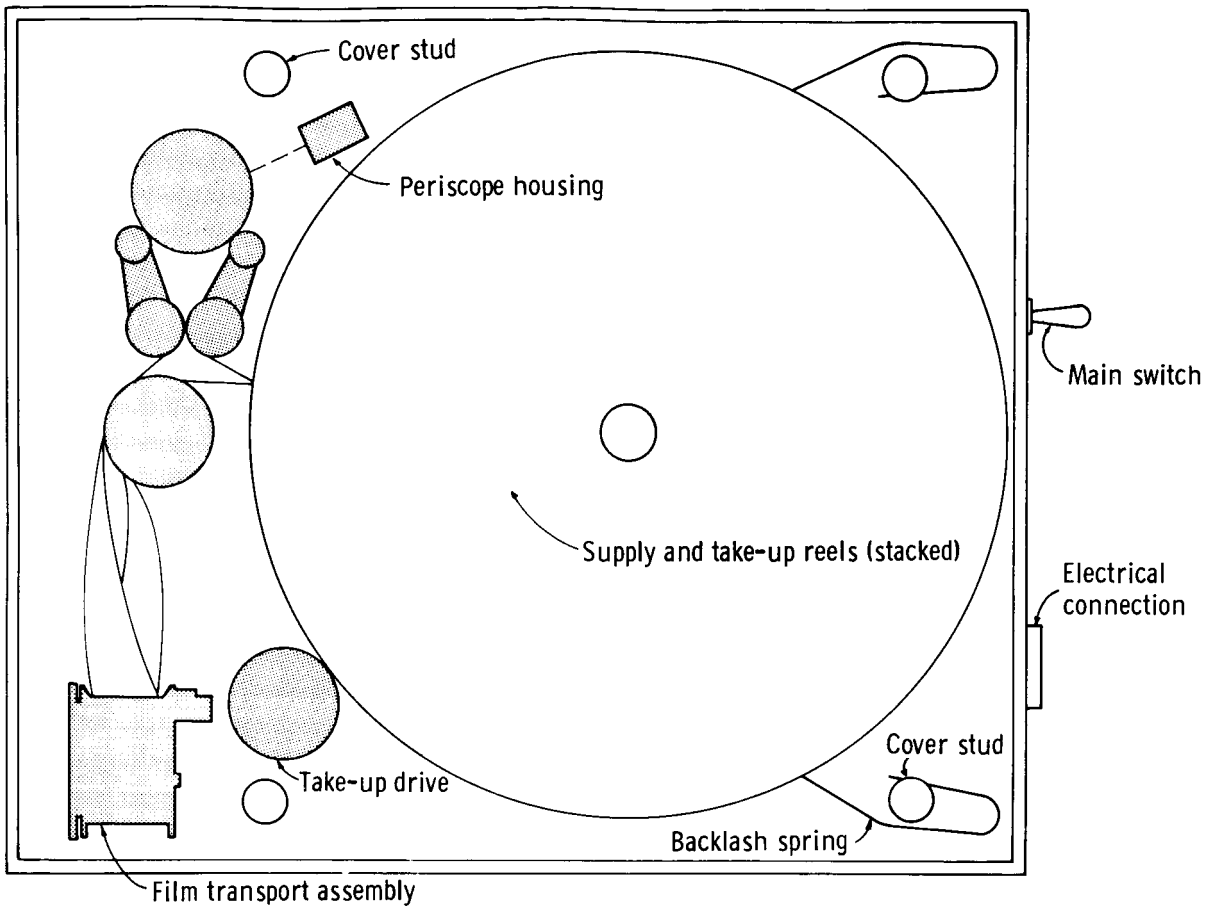
(a) Photograph.

FIGURE 11–4.—Oscillograph showing the bases of the two springs holding the film to the large 400-foot reels on the left side. The rubber-rimmed drive wheel is two-thirds visible at 8 o'clock on the spool. The film loop winds under a series of small spring-loaded rollers and passes over a large roller at the lower left to receive the beams from the galvanometers. This light is passed through from the reverse side of the oscillograph by the "periscope" seen at 11 o'clock on the reel.

estimated from the slope of the curve. Figure 10–2 is a composite graph of the physiological data including the blood pressure observations. It demonstrates that the ectopic beats experienced by the subject produced the anticipated insignificant momentary drops in the vascular pressures.

## Discussion

The technique for recording the vascular pressures was entirely satisfactory. The data obtained are difficult to evaluate without further control observations on the flight subject and other chimpanzees. The diastolic and systolic systemic arterial pressure was high throughout the flight while the pulse pressure was low. It is a true observation and cannot be attributed to instrumental difficulties since the pressure recordings were uniformly good during the entire 3 hours of pad observation, and yet the values were of the same order as those obtained during flight. These high prelaunch arterial pressures were not peculiar to those obtained on the flight day but were within the range noted at times of physical examinations for this particular chimpanzee (fig. 11–7). Figure 11–7 shows the mean blood pressure of the five flight animals while in training at the Aeromedical Research Laboratory. The vertical bars indicate mean systolic and diastolic pressures. There is great variability in all values, including those for the quarterly physicals which run somewhat higher for the MA–5 flight subject than the rest of the group and fell well within the values obtained immediately preceding and during the orbital flight. The bars labelled Jim and Enos data acquisition flight indicate the responses of the flight subject (Enos) and one




(b) Schematic diagram.

Figure 11–4.—Concluded

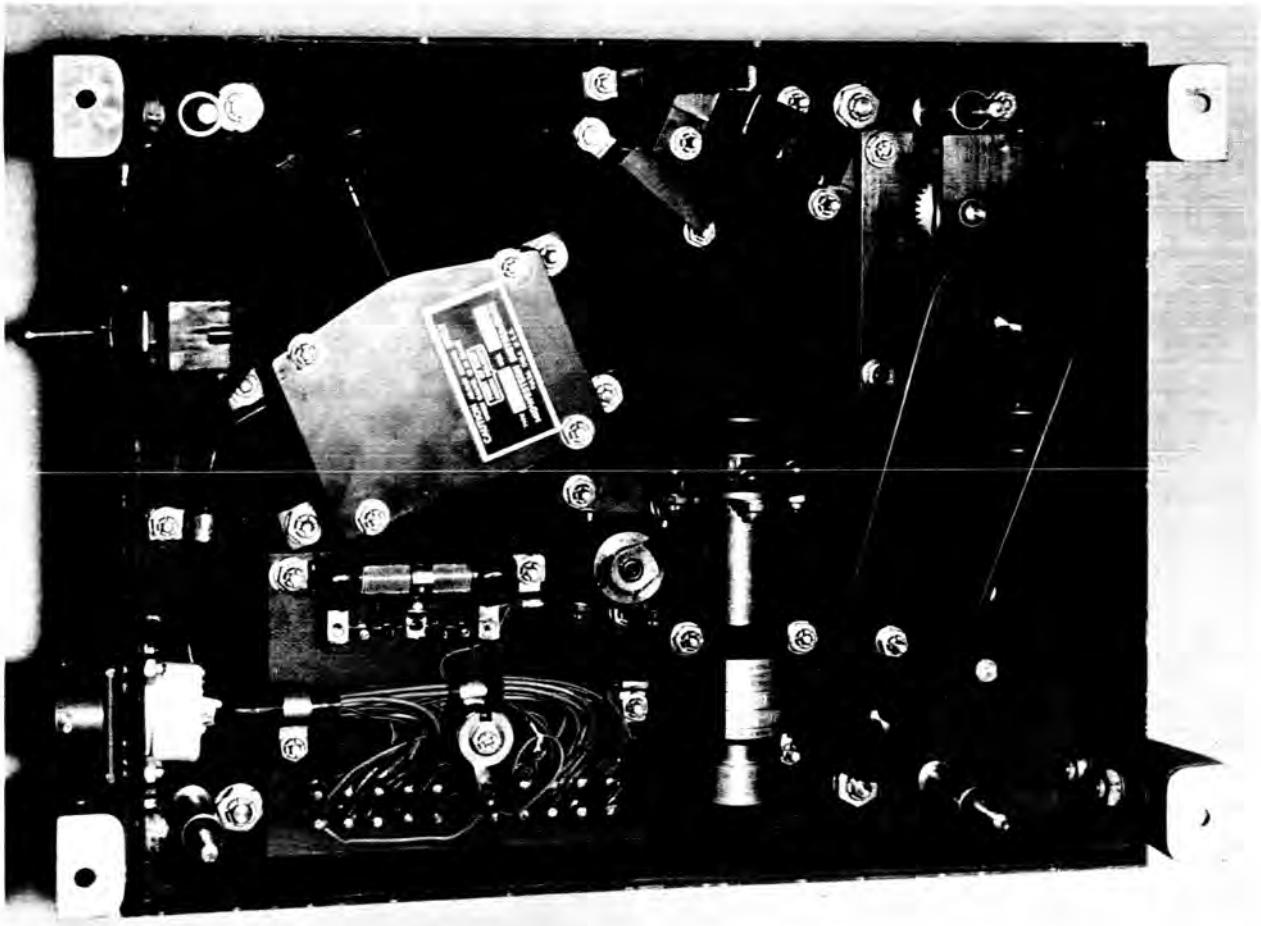
other animal (Jim) to aircraft flights with the animal in the couch. These flights were aimed at indoctrinating them to the distraction of rocket flight. The high data acquisition value in July 1961 corresponds to information gathered during the flight, and the low value following it corresponds to measurements made following return to his customary environment. The data of figure 11–7 indicate that the flight subject has a labile systemic blood pressure and that values of the order of 160 to 200 mm Hg systolic had been observed by sphygmomanometry during the 2 years preceding the flight. The animal had an elevated systemic arterial pressure at the time of the flight, and further investigation conducted on the centrifuge subsequent to the flight has shown that the subject continues to have an elevated systemic pressure. The data included comparative studies on and off the centrifuge both with and without arterial catheterization. It is not known to what extent the elevated pressure is due to the effects of psychological training and to what extent it is inherited.

The pulmonary arterial diastolic pressure was somewhat elevated with a consequent reduction in pulmonary arterial pulse pressure and there was a small but significant rise from the control period on the launch pad to the records obtained in flight. The pressures in the venous tree and the pulmonary vascular bed, appeared to be parallel. (See ref. 2.) Despite the rise of approximately 10 mm Hg in diastolic pressure, the data obtained from the pulmonary artery during this flight point to no gross abnormality in the functioning of the low-pressure portion of the cardiovascular system. The systemic arterial pressure responded normally to the periods of launch and reentry acceleration and, in fact, showed a moderate decline during the 3-hour period of weightlessness despite the failure of the center lever and the consequent repeated shocks.

## References

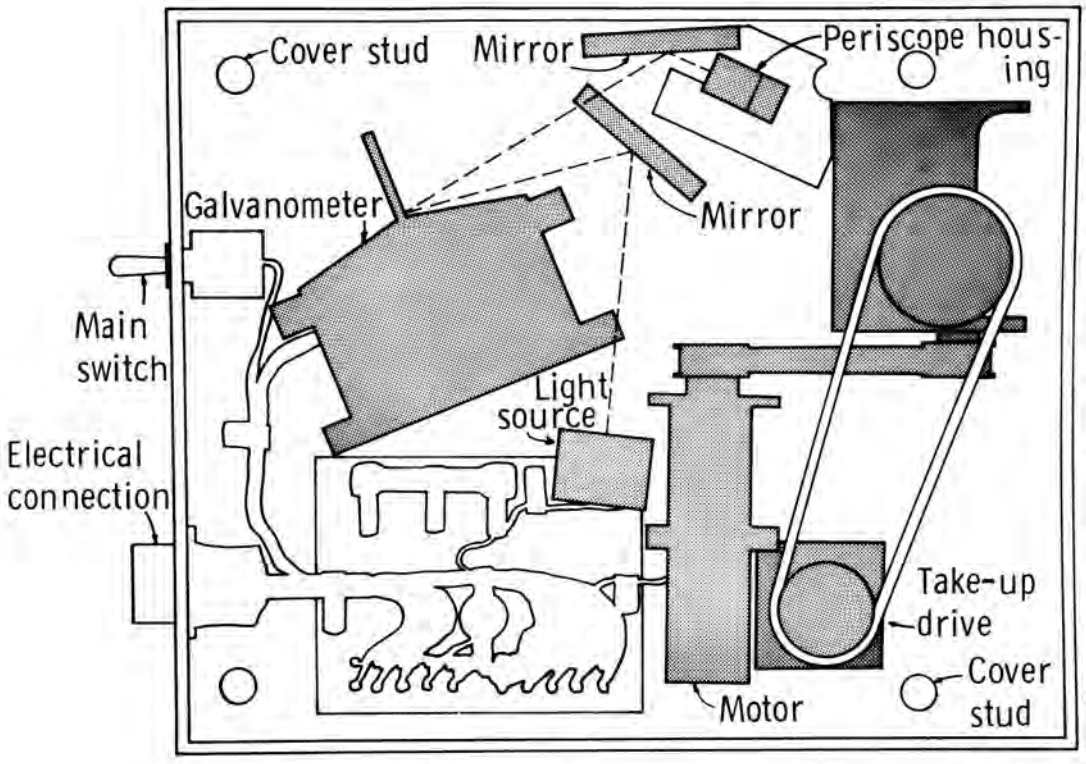

1. Henry, J. P., Ballinger, E. R., Maher, P. J., and Simons, D. G.: Animal Studies of the Subgravity State During Rocket Flight. Jour. Aviation Med., vol. 23, no. 5, Oct. 1952, pp. 421–432.

2. Henry, J. P., Bauer, O. H., and Sieder, H. O.: The Effect of Moderate Changes in Blood Volume on Left and Right Arterial Pressures. Circulation Research, vol. 4, 1956, p. 91.

(a) Photograph.

FIGURE 11-5.—Reverse side of the oscillograph showing the galvanometer block (middle upper left) with on-off switch nearby. At the lower left are the electrical connections for the galvanometers and the lamp. To the right and next to the lamp is the drive motor, with a flat rubber belt connecting it to the reduction gear which in turn actuates the rubber spool drive wheel by a round rubber belt. The two mirrors folding the beam and the "periscope" diverting the light to the other side of the oscilloscope are seen in the upper portion of the photograph between the drive gears and the galvanometer block.




(b) Schematic diagram.

Figure 11-5.—Concluded

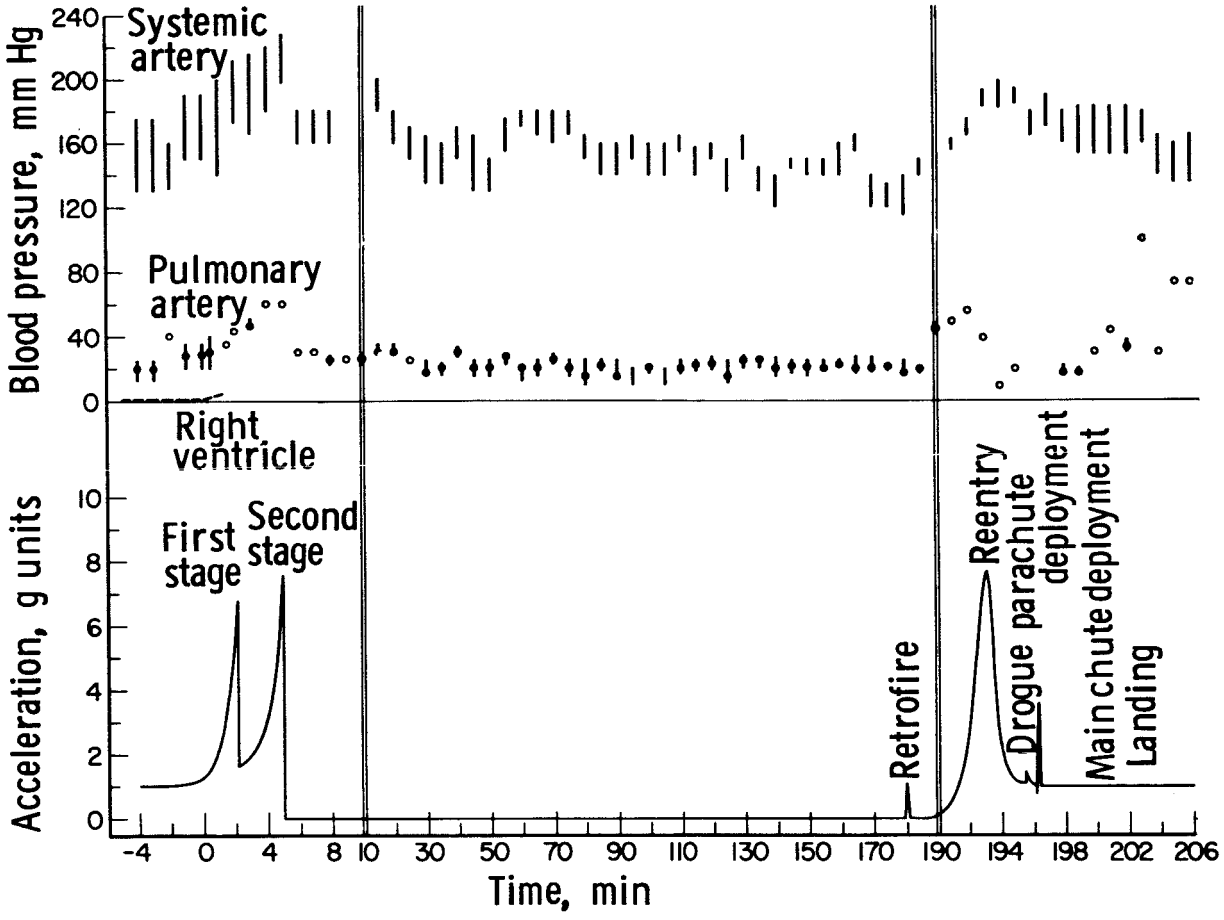



FIGURE 11-6.—Blood-pressure response of the MA-5 flight subject. The bottom trace is the record of the acceleration transverse to the animal's body. Above this trace are the pulmonary-artery and right-ventricular pressures. The vertical bars represent the pulmonary arterial systolic and diastolic pressures as read on the sensitive galvanometer and the circles the pressure from the less sensitive galvanometer which was connected to the same gage. Systemic arterial pressure which is depicted by the same convention is shown on the top row. Notice the normal return of the pressure to prelaunch values during the period of weightlessness and the rise to higher values following reentry. During the 0g period of flight, arterial systoles exceeding 160 mm Hg were estimated from the slope of the wave.

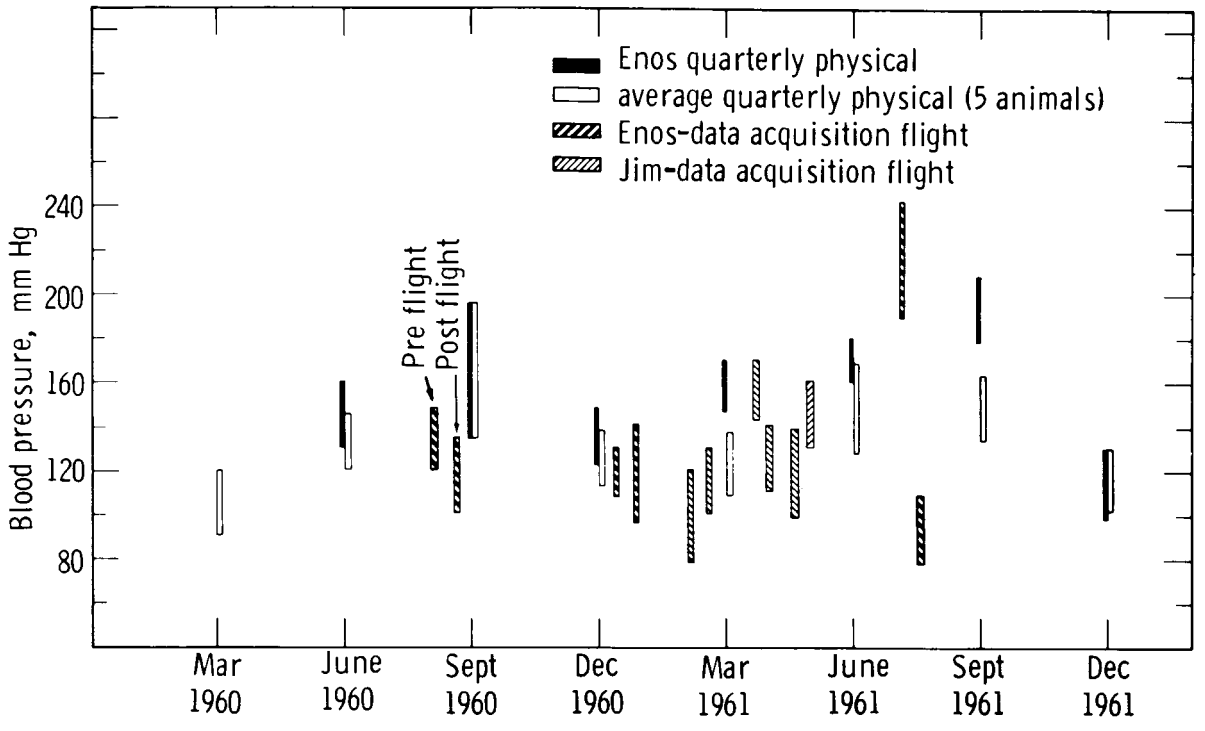



FIGURE 11-7.—Bar chart of the mean systolic (top end of the bar) and diastolic (bottom end of bar) pressures obtained during the period of training of the five flight animals at the laboratory. The values show great variability, and the range covers values for the MA-5 subject on the launch pad and flight. The bars labeled Jim and Enos data acquisition flights represent pressure measurements made during and after airplane flights indoctrinating the animals to the distracting noise and vibration while at work in the flight couch.

# 12. SUMMARY OF THE RESULTS *of the* MA-5 FLIGHT

By John D. Mosely, D.V.M.,* and
James P. Henry, M.D., Ph. D.**

The results of the data analysis have been presented in previous sections of this report; however, several of the inflight and postflight events warrant further comment. Premature ventricular contractions (see fig. 10–1) were first noted by the medical monitor at the Zanzibar tracking station at launch (T) plus 26 minutes. Since launch acceleration lasted for 5 minutes, the first premature ventricular contraction occurred after 21 minutes of weightlessness. The premature ventricular contractions continued singly, in pairs, and in runs until T+3 hours 15 seconds. At that time, the retrorockets were fired and from then on the subject was subjected to increasing accelerations. Continuous data on the subject covers the period from T−5 hours 30 minutes until T+3 hours 21 minutes. Premature ventricular contractions were present from T+26 minutes until T+3 hours 15 seconds. (See fig. 12–1 in which premature ventricular contractions are plotted against time.)

The subject's blood pressure was recorded onboard the spacecraft but was not monitored by telemetry; therefore, no data were available until after the flight. Although the blood pressure was high (figs. 10–2 and 11–6) it was not inconsistent with the preflight values which were also high nor was it inconsistent with some of the data obtained previously on this subject (fig. 11–7). Also presented in figure 11–7 are the blood-pressure data of five other chimpanzees trained for Project Mercury. These subjects received similar care and were exposed to the same training as the flight subject. It must be noted that the flight subject is one of the most excitable animals in the Aeromedical Research Laboratory in his age group and usually requires maximum restraint during a physical examination.

Figure 12–1 was prepared to determine if performance or shock was a factor in inducing premature ventricular contractions. It can be seen that they occurred at random during each task as well as during the rest sessions. It has not been possible to demonstrate any correlation with events during the flight except that the premature ventricular contractions only occurred during the weightless state. It may be speculated that they were associated with some changes in the position of the catheter in the heart during weightlessness. The physiological and psychomotor responses to the flight were as expected except for the sustained high blood pressure. This condition preceded the flight and was not due to the act of catheterization or to the presence of the catheters in the leg artery and vein. For example, subsequent studies have shown no increase in blood pressure, with values obtained being the same as those measured by sphygmomanometry.

The subject performed as desired throughout the launch and reentry acceleration and during the weightless state despite the unplanned stress caused by the failure of the center lever in the psychomotor apparatus which resulted in the numerous shocks during the oddity problem presentation. Subsequent to the oddity presentations, performance was within normal limits except during the peak acceleration of reentry. The data show no significant disturbance either in his behavior or physiology that could be attributed to the weightless state, to the other conditions accompanying the flight, or to the lever malfunction during the second orbital pass. As can be seen from figures 12–2 and 12–3, which show the orbital flight subject immediately before the countdown and just after recovery, his post-flight appearance supported the physiological and psychomotor data.

Nevertheless, the extra systoles and the high blood pressure do point up the importance of measuring the

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total subject response in terms of both behavior and physiology. Both approaches are required to evaluate the flight or any particular portion of it. That the psychological task recordings showed normal performance despite the cardiovascular irregularities was convincing evidence of the immediate value of the operant technique as a direct measure of the well-being and performance capability of the subject.

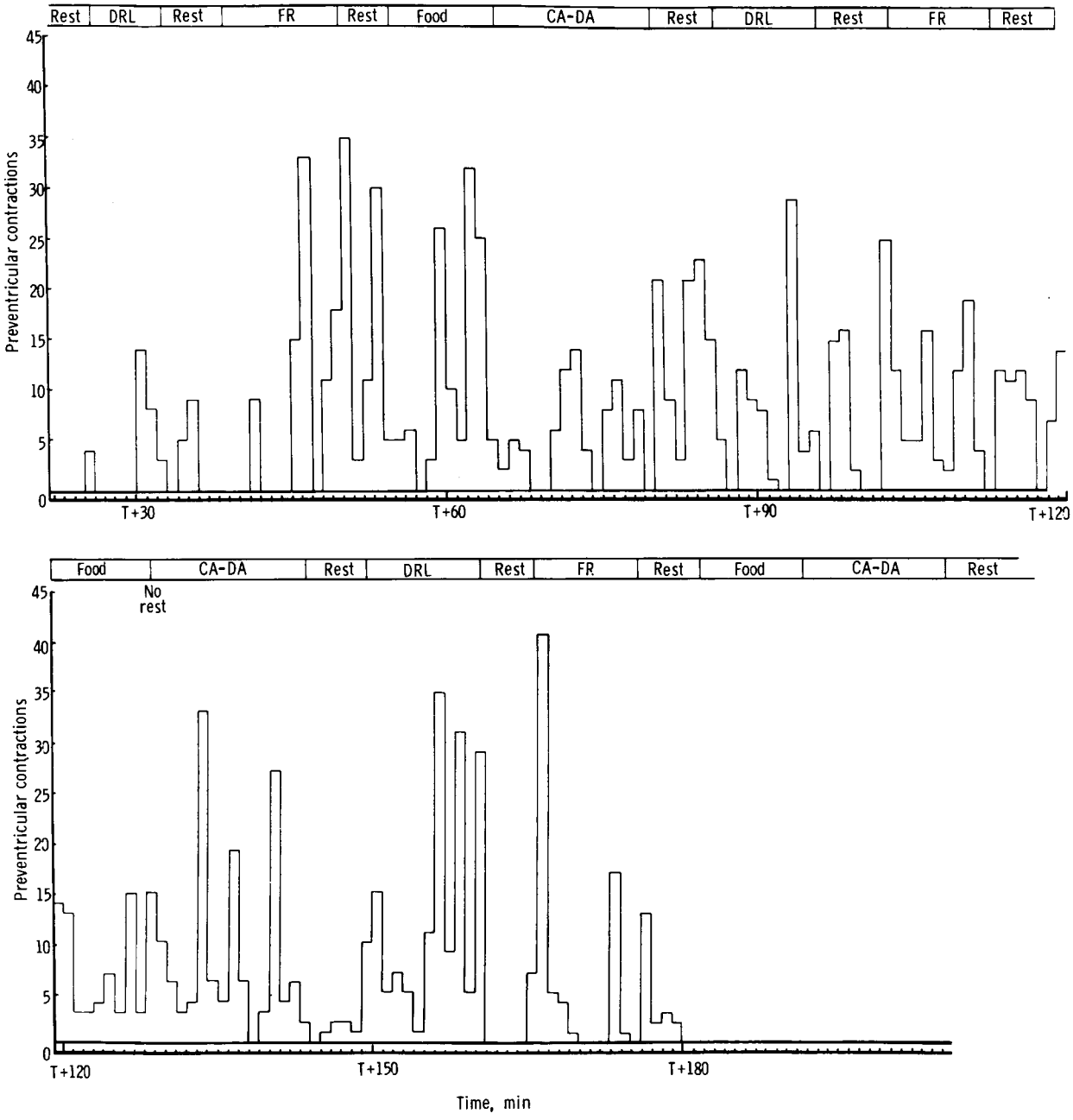



FIGURE 12-1.—Preventricular contractions plotted against time. Chart shows that the incidence of preventricular contractions appears to be unrelated to events in behavioral performance schedule of the animal including the failure of the center-lever switch with the consequent high incidence of shocks during the second part of the weightless period.



FIGURE 12-2.—The MA-5 flight chimpanzee immediately before the countdown. Note the restraint garment with its adjustments at the side.



FIGURE 12-3.—The MA-5 flight chimpanzee photographed at the launch site 2 days after recovery.



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